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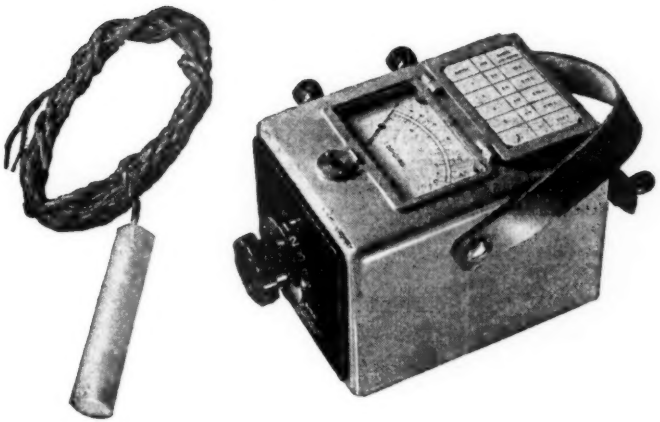

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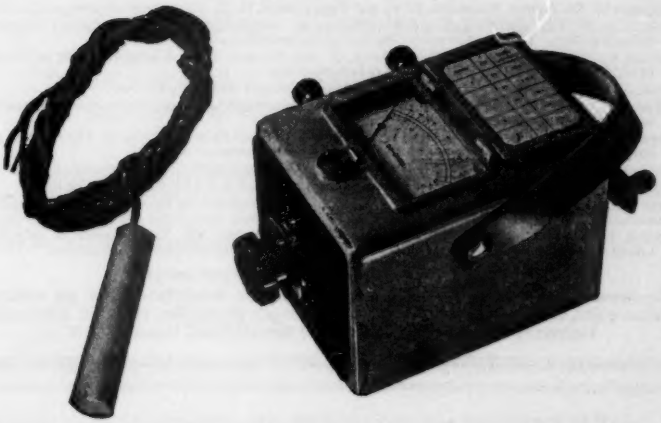

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THE SIGNIFICANCE OF CYCLIC PEAK YIELDS IN NIGERIAN OIL PALMS

WILLIAM B. HAINES

(Rothamsted Experimental Station)

Summary

An investigation into individual palm yields on the Unilever experimental plots in Nigeria has shown a very distinct rhythmic occurrence of peak yields. Superior years stand out clearly and have occurred most frequently at three-year intervals; but this extends sometimes to four years, and also the peak may last over two consecutive years. On average the peak yield is about 80 per cent. above the mean yield for the palm. The two intervening years between peaks seem about equally bad.

The explanation advanced is that the recurring fruiting phase of the palm has a shorter natural period than the weather, so that if there is [illegible]

CORRIGENDUM

In the paper by John G. Ross on 'A classification of Zebu cattle types in Teso District, Eastern Province, Uganda' (Vol. XXVI, No. 104, p. 298), the descriptions of Figs. 5 and 6 (Plate 8, facing p. 308) should be interchanged thus:

Fig. 5. Necked horn.
Fig. 6. Long horn.

Similarly, on p. 302:

in line 17, for Fig. 5 substitute Fig. 6.
in line 21, for Fig. 6 substitute Fig. 5.

determination of sex in the flower primordia (distinctly alternating between F and M) and the cutting of the fruit at maturity is 30–32 months, i.e. just half the five-year cycle. If it can be assumed that the function of bearing a good crop causes some reaction in the palm tending to greater maleness of the primordia then being formed, there will be an inversion in yield thirty months later, and the action will repeat to complete a cycle in five years. The strongest initiation of such a rhythm would be the first coming into bearing of an area, and the yields of Calabar Estate shown in Fig. 1 seem to be a good example of this. In addition the figure shows data from two other cases [2], plotted so that the time axis shows one common minimum for all curves.

There is a second mechanism, which seems very much more fundamental than the above, which gives a shorter cycle of three (or sometimes

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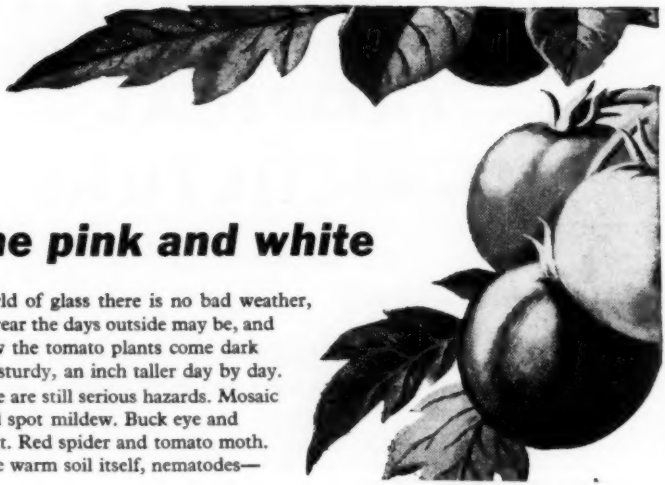

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THE SIGNIFICANCE OF CYCLIC PEAK YIELDS IN NIGERIAN OIL PALMS

WILLIAM B. HAINES

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The explanation advanced is that the recurring fruiting phase of the palm has a shorter natural period than the weather, so that if there is a conjunction of palm phase with weather which falls propitiously in some years, it will be likely to fall adversely in others in a manner that recurs with regularity. The peak years seem to correspond with normal behaviour of palms suffering no abortions, so that off-years may be regarded as losses. These would have some prospect of being prevented by remedial action if the vulnerable phases can be identified.

The mechanism seems to be quite fundamental, for no first-order influences on the rhythm from manuring treatments, block sites, or variety of palm have been detected.

THE data provided for the present investigation comprise the annual individual yields for fourteen or fifteen years from upwards of 3,000 palms. These were the twenty-four inside palms of each plot in five manuring experiments conducted by the Unilever organization in Nigeria and known as Cowan 1, 2, 3 and Ndian 2, 4. In addition the monthly bunch numbers of Cowan 2 were used for the seasonal effects. In a previous communication [1] attention has already been called to the rhythmic nature of oil-palm yields, and the purpose of this paper is to amplify those observations. The rhythms seem to evince themselves in two distinct ways. The first is a five-year cycle frequently noticed in yield data from large areas. This might have an explanation in the physiological sequences in the palm itself, for the time between the determination of sex in the flower primordia (distinctly alternating between F and M) and the cutting of the fruit at maturity is 30–32 months, i.e. just half the five-year cycle. If it can be assumed that the function of bearing a good crop causes some reaction in the palm tending to greater maleness of the primordia then being formed, there will be an inversion in yield thirty months later, and the action will repeat to complete a cycle in five years. The strongest initiation of such a rhythm would be the first coming into bearing of an area, and the yields of Calabar Estate shown in Fig. 1 seem to be a good example of this. In addition the figure shows data from two other cases [2], plotted so that the time axis shows one common minimum for all curves.

There is a second mechanism, which seems very much more fundamental than the above, which gives a shorter cycle of three (or sometimes

[Empire Journ. of Exper. Agric., Vol. 27, No. 105, 1959.]

four) years. It may be noted that the climate of Nigeria shows one intense dry period in December–January and effectively sufficient rain during the rest of the year. There can be no doubt that the drought strongly affects the palms. In the palm itself the fruiting (F) phase alternates with the M phase and repeats most commonly with a period of nine months. If then some special phase of development of the fruit is suited best by a certain phase in the weather cycle, these can synchronize every third year and fail to do so in between. In other words, there

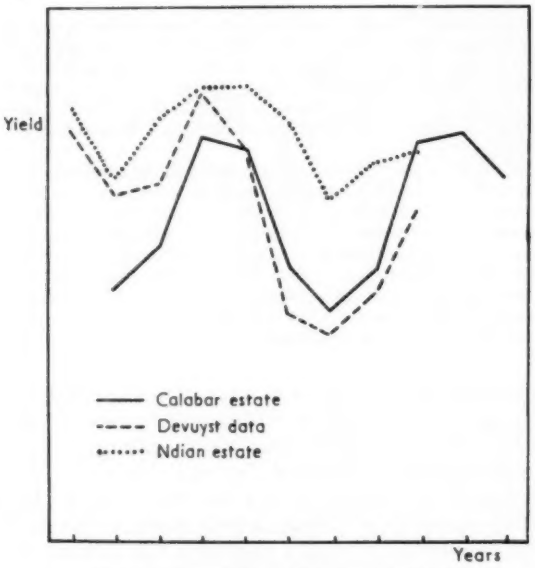

FIG. 1. Examples of five-year rhythm.

will be a 'beat' between a 9-month and a 12-month periodicity. If the period of the palm is reduced to eight months, the beat will be in alternate years, and if it increases to ten months the beat is five years. The steady maintenance of the period of the palm is probably linked with rate of growth or appearance of fronds (i.e. temperature as well as rain comes into consideration there).

Proof of the Three-year Cycle

The merest inspection of the yield tables is sufficiently convincing of the rhythmic nature of oil-palm yields in this climate. In Fig. 2 are inset the yield curves of four palms chosen to exhibit the typical behaviour to the best advantage. The occurrence of peak years standing out from the others is quite characteristic. Most usually the period between them is three years, but sometimes it is four years, and sometimes the peak lasts over two consecutive years. A count of intervals was made in the data for a single block (about 200 palms recorded for fourteen years) and gave the distribution shown in Table 1.

It is clear that the three-year cycle greatly predominates. In 21 per cent. of cases the propitious circumstance (whatever it may be) continues for two consecutive years and in a closely similar number the peak is deferred from the third to the fourth year. Only 12 per cent. of cases fall outside these three categories. No clear differences were shown from the plot treatments.

TABLE 1. *Time Distribution of Peak Yields of Oil Palms*

	Peaks in consecutive years	*Recurrence of peaks in*			
		2nd year	*3rd year*	*4th year*	*5th year*
Percentage of cases	21	7	48	19	5

Blocks of palms tend to keep in phase so that total yields of even large numbers reflect the rhythms. It is not likely that deviations from the regular weather cycle would be clearly rhythmic, but it is natural to think that these deviations could be the cause of the good and bad years. The argument is not clear until these good and bad years are formally equalized. Since palms with peaks can be found in all years, whether generally good or bad, a smoothing can be effected by choosing a sample of palms which will equally represent each year in a sequence. Specifically, one palm was chosen with a peak for each of the three (or four) middle years in the records of each plot of an experiment, giving a sample of 1 in 8 (or 1 in 6). The peak in each case was taken as a zero time datum and the histories so combined as to give the average yields at 1, 2, 3, ... years remove from this datum. This smooths the yearly influences as if by a running mean, and leaves the natural behaviour of the palm clearly revealed. The results for three experiments are shown in Fig. 2. The linear regression with time has been taken out and the figures expressed as deviations from the mean. The peak is some 80 per cent. above the mean, and the tendency to recur at the third remove is very clear. The two intervening years are about equally bad. The three curves represent differing soil types, two regions of Nigeria, and two palm varieties, and their close similarity shows how fundamental the mechanism must be. In the fourth position we have some palms in their second depression and others in which the peak has been deferred, and the deviations about cancel out. In the fifth position these groups are both in their second depression and pull the average down. Since such 'scrambling' of rhythm begins in the third remove and goes on increasing, pursuit further from the datum is likely to be fruitless.

A similar figure was produced for Ndian 4 using all the palms. This could not have strict regard for years (good or bad, so called) being equally represented in each position, but this is now shown not to be important for the argument. This work revealed that the sample used in Fig. 2 correctly represents the average amplitude of movement, but by some means the special choice had lessened the emphasis on the fourth year. In the curve for all palms the fourth position on either side

of the peak shared the honours with the third, which might be expected from the distributions shown in the first table. This fuller treatment was carried out, partitioning by plots, without revealing any marked influence of the main treatments on the rhythms. The formal analysis of variance made possible by such treatment revealed very high significance (t values as high as 9) for the deviations now discussed.

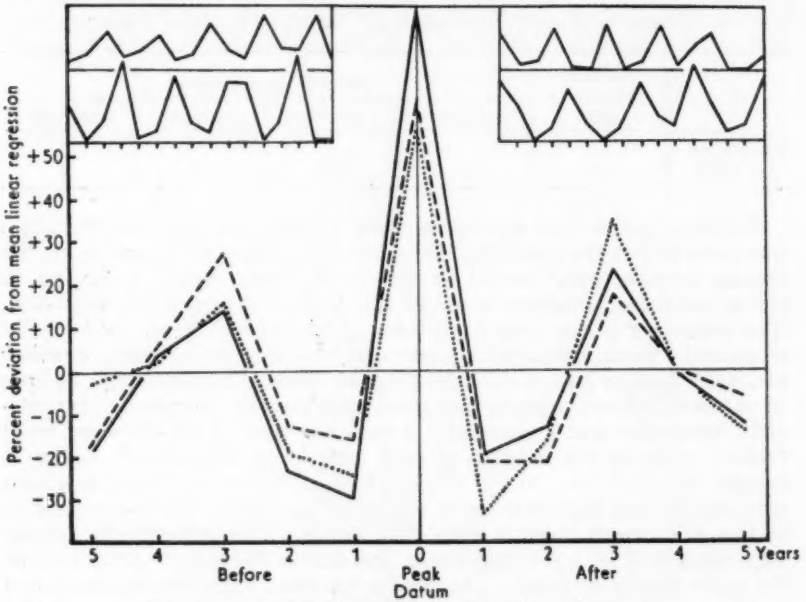

FIG. 2. Fundamental recurrence of peak in third year.

Seasonal Development

In one experiment the bunch numbers recorded for every month were available. It was therefore possible to examine the seasonal relationships between the peak year and the years before and after. This has been done in Fig. 3 for a sample of six palms per plot (162 in all). The first point to notice is the very distinct division which the dry period December–January effects between the annual results. Since a good-yielding flush lasts for four or five months it might have been expected (in absence of seasonal influences) that the average of a number of years chosen for exceptional yields might have overlapped or spilled over into the adjacent months of the next calendar year. But this is not so. The dry period forms a very definite natural break in yields. In the datum year there is a very large seasonal response with the highest yield in May, while in the other years the bunch numbers are more indifferent to season. We may trace back ten months from the May peak and notice that in the preceding July there is a smaller peak corresponding to the F cycles previous to those producing the May peak. But the shift of

two months in the relationship to the annual rain cycle has damped the response. In the year after the peak the F cycles appear to have lost step.

As a preliminary to any attempt to interpret these facts the conception of a standard palm was introduced, that is, a palm of regular and typical growth unhampered by any abortions or other vicissitudes. This standard is supposed to produce twenty fronds per year with a fully functional flower in each axil. M and F cycles are supposed to alternate

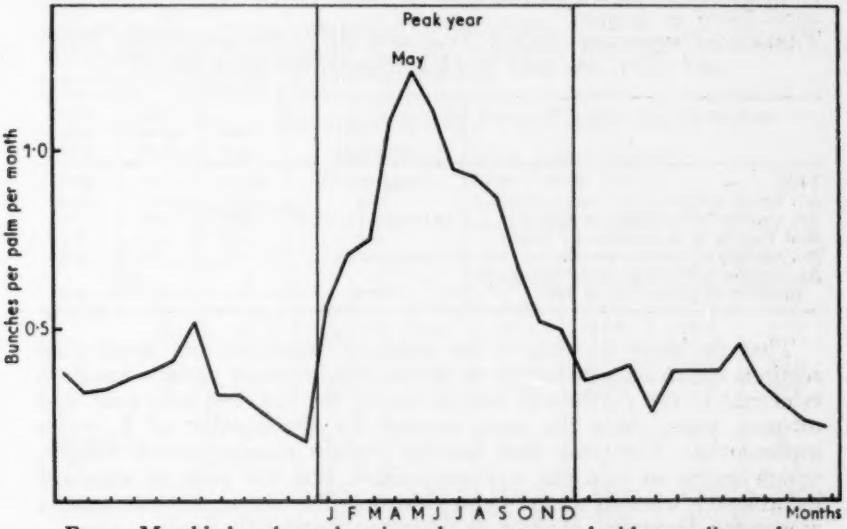

FIG. 3. Monthly bunch numbers in peak year compared with preceding and succeeding years.

with a common period of 4½ months independently of any seasonal influence. The *average* annual number of bunches would be ten. The standard bunch weight may be taken as 14·5 kg. This standard behaviour would show a three-year cycle with a maximum year of 7·5 yielding months (one M period and portions of two F periods giving 182 kg.) and a minimum year of 4½ yielding months (giving 109 kg.). This is compared with the actual data which provided Fig. 3, in Table 2. The convention was adopted that a gap of one month in bunch production was not a break in the F cycle, but that two or more months' interval represented an intervening M cycle with a new F cycle following.

It appears from the last line of the table that in all cases the regular appearance of the F cycles agrees, but that, while in the peak year the behaviour is remarkably like the standard, there is a serious falling off in fruit in the years before and after (not much more than half of the expected minimum for the standard palm). In regard to the production of a three-year rhythm in the standard behaviour by the mere division of a sequence of 4½ fruiting months alternating with 4½ non-fruiting months into twelve-month periods for recording purposes, there is a

strong contrast between this ideal and the actual behaviour shown in Fig. 3. The best year for the standard (supposed independent of season) is one in which two fruiting periods (perhaps overlapping into the next year) are separated by one M period, and this would, on average, give a monthly distribution in a peak year with a minimum at the mid-year and maxima at the beginning and end. This is the inverse of the actual curve, and shows that the rhythm is developed from the fact that the twelve months holds a strong cyclic weather influence.

TABLE 2. *Comparison of Peak Year with the Years Immediately Before and After, and with an Ideal Standard (Cowan No. 2)*

	Standard	*Peak year*	*Year before peak*	*Year after peak*
Yield	range 109–82	157·7	57·6	56·5
Av. bunch weight	14·5	15·7	14·2	14·4
Av. number of bunches per annum	10 (range 7·5–12·5)	10·0	4·0	3·9
Best F cycle in 12 months, av. length	4·5	5·6	2·3	2·4
Av. number of fruiting months	6 (4·5–7·5)	6·0	2·8	2·8
Av. number of fruiting runs represented in whole or in part in one year	1·7	1·7	1·7	1·7

That the mere division of the standard sequences into equal time sections which include longer or shorter total fruiting periods has little relevance to the rhythms is also shown by the fact that both peak and off-peak years show the same average for the number of F cycles represented. The peak year has the highest average bunch weight, which seems to rule out any supposition that the peak or standard behaviour is a strain on the palm (which could, if true, be accounted a reason for depressive reaction in the other years).

The proper conclusion seems to be that every third year the phases of the palm find a propitious synchronizing with the weather cycle and the behaviour is normal, while in intervening years there is a disjunction and serious losses due to antagonistic features (abortion of flowers).

To illustrate the approach to finding an explanation it may be stated that the seasonal yield curve in the peak year follows closely the inverse annual rain curve with a displacement of $4\frac{1}{2}$ (or $16\frac{1}{2}$) months. This latter period is that between the first appearance of the F flower spike and its final ripe fruit, i.e. the bunches being harvested so profusely in May are from flower spikes which first appeared in the dry season at the beginning of the previous year. This might well be a propitious conjunction. The fertilizer treatments have also been given in the dry season, but since treatments have not been found to affect the rhythm at all fundamentally this aspect is not to be emphasized. The rain season is long and not so sharply marked as the dry season, and it is therefore less easy to try to fit this to other events in the fruit development as alternative explanations of the mechanism.

Success in the search for an explanation of the exact mechanism might be very rewarding, if it led to marking down special sensitive phases in the palm for protective treatment. The opportunity to make every year

a peak year, which seems to find no physiological barrier, would, on the data of Table 2, increase the average crop by 74 per cent., a very ample reward even if only partially secured.

Partitioning of Palm Classes

It will be apparent that the endeavour to classify palms into high- and low-yielding groups is made very difficult by the great amplitude in the annual fluctuations of each palm. A short period (three years say) might happen to contain two peak years or none at all, giving an untrue indication as to the average capacity in either case. Indeed, to cover these uncertainties and to classify a palm properly, requires records of a considerable fraction of its economic life.

TABLE 3. *Yield Characterization of Seven Classes: kg./palm/ann.*

A period provides classification: *Cowan 5 years 1942–6*
Ndian 6 years 1940–5

B period ensues: *Cowan 8 years 1947–54*
Ndian 10 years 1946–55

Class		*1*	*2*	*3*	*4*	*5*	*6*	*7*
Cowan 1	A	77·5	63·8	56·8	49·4	41·8	30·0	16·8
	B	82·2	75·1	72·9	60·3	62·4	49·5	31·3
Cowan 2	A	84·9	69·6	61·9	52·6	46·5	33·4	18 4
	B	90·0	80·2	81·5	69·2	65·0	55·6	39·0
Cowan 3	A	88·1	73·0	64·7	56·5	48·6	37·3	20·4
	B	95·9	91·0	77·7	67·0	62·7	54·0	35·2
Ndian 2	A	99·9	86·1	78·0	69·3	59·6	48·2	29·5
	B	87·9	78·0	74·3	70·9	65·1	54·8	40·6
Ndian 4	A	89·2	72·7	62·0	56·2	49·2	42·2	32·1
	B	85·5	74·9	67·4	62·7	57·1	49·1	35·4

Some work has been done on the records by classifying the palms on the first five years' results, referred to as the A period. The twenty-four palms of each plot were in this way placed in order of merit, and the suppositions made that the differences are mainly genetical and that all plots originally had a similar random sample of genetical material at planting. Of these twenty-four categories the lowest three were discarded as unlikely to be of use, and the others grouped into threes to give seven classes for study. Thus Class 1 in each plot is the average of the best three performers in the first five years of the records. This corresponds to the early period in wartime, when fertilizers were not readily available and the treatments scanty, so that the classification is presumed not to be greatly influenced by treatment.

The plot values within the classes can be examined (for the period B following the years used for the grouping) for treatment effects, and this would show any outstanding differences in the responses of good or bad palms. It is a natural reflection when examining an experiment to

wonder whether fertilizers are not wasted on the poor yielders. Cowan 2 has already been reported as showing, contrary to the above conjecture, that the poorer classes have a higher requirement for potash than others and make better response. Out of the other four experiments now examined one repeated this feature to a lesser degree and the others not at all. The safest generalization is that there are usually no grounds for fearing that a uniform distribution of fertilizers is wasteful. The only other feature of note concerned the P×K interaction in the Cowan experiments. Here the use of phosphorus without potassium proved

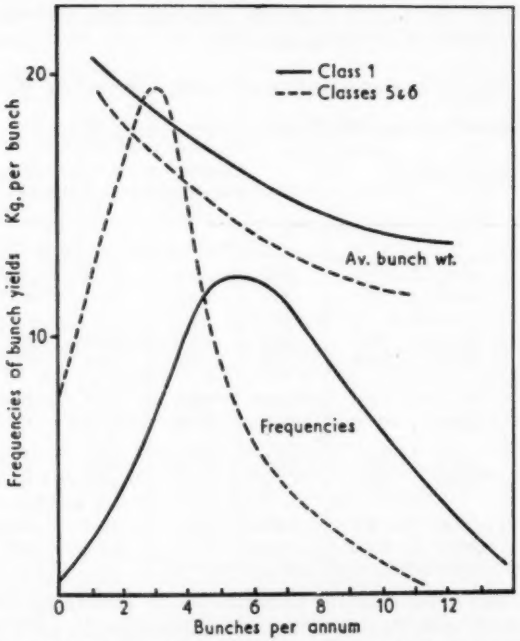

FIG. 4. Relationship of bunch weight to number of bunches carried.

beneficial for the better palms (classes 1–3) but deleterious to the lower classes. Lower classes possibly have more incipient root disease. In the presence of potassium, phosphorus was beneficial to all classes except class 7.

In the Cowan 2 experiment the classes were examined to test how far years of large bunch numbers are accompanied by a fall in bunch weight, the point of interest being to decide how far bad years might be considered a necessary physiological reaction to the good. The fact that two peak years in succession can occur in 21 per cent. of cases (Table 1) is against any theory of depressive reaction, and the rest of the work tends to confirm the rejection of such a view. The frequencies with which the palm classes produce 0, 1, 2, 3, &c., bunches in the year were

ascertained and the corresponding average bunch weights calculated. Fig. 4 shows a comparison of the results between class 1 and classes 5 and 6 taken together. Class 1 produces heavier bunches, but the yield superiority comes mainly from the larger numbers of bunches. Although bunch weight falls when larger numbers are carried this feature is not strongly marked; apparently the crop may be increased by *four* times while the average bunch weight is reduced by only one-third. The implications of this are most important. It suggests that if flowers can be suitably protected and nurtured to prevent abortion, the palms seem fully capable of continuously carrying the larger crops which the other considerations have shown to be normal.

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THE EFFECT OF GRAZING MANAGEMENT ON THE RESPONSE OF WINTER WHEAT TO SPRING DEFOLIATION

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Summary

Winter wheat was clipped in spring in all combinations of three clipping dates separated by 7-day intervals. Clipping resulted in a reduction in the yield of straw, but a single clipping on the second or the third dates increased grain yield and size. Repeated clipping reduced yield and grain size to a level similar to that of the control. It is suggested that continuous grazing of cereals at low stocking rates may result in repeated defoliation with consequent damage. A field experiment comparing continuous grazing with folding was inconclusive.

THE practice of grazing winter-sown cereals in the early spring months has been widely known for many years. Only recently, however, have attempts been made to measure the effects of this treatment experimentally and to explain and anticipate them. Peto [1] carried out a detailed study at Wye College, and Holliday [2] has recently reviewed the literature on cereal grazing. Under field conditions grazing is sometimes beneficial, giving increased yields, while in other cases losses in yield are the rule. The experimental evidence reviewed by Holliday makes it possible to formulate the following general conclusions:

1. Increases in grain yield normally occur only when soil fertility conditions are so good that lodging would take place if the crop were not grazed. Grazing gives a shorter straw and thereby confers a resistance to lodging.

2. Under conditions of average or low soil fertility, losses in yield may be expected to result from grazing.

3. The effects of grazing are more severe the later in the season it takes place and become extremely harmful if delayed until the growing-point has elongated sufficiently to become susceptible to damage. In England this stage is usually reached some time during April, depending on season and variety.

Much of the experimental work has been directed at the practical problem of how to get the maximum amount of grazing with the minimum loss of grain yield. The stage of growth at which the crop is grazed has been shown to be of great importance by many experiments. Peto [1] has studied the use of nitrogenous fertilizers to encourage rapid recovery in growth. However, little has been done on the effect of method of grazing on cereal growth and grain yield. It might be expected that continuous grazing over a period of a week or more would result in weakened plants due to the continual grazing of the fresh growth while, on the other hand, a quick on-and-off grazing technique involving a higher density of stock for a shorter time might do less damage. This has been

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found to be so with lucerne, and is one of the justifications for the development of systems of strip grazing in grassland management.

Cutler, Pavez, and Mulvey [3] have described experiments in Indiana, U.S.A., which involved mechanical clipping of wheat at various combinations of four dates in April at 9- or 10-day intervals, and although the authors did not discuss the significance of multiple clippings, it is clear from their results that clipping on up to four occasions at 10-day intervals had no more serious effects on wheat growth and development than a single cut on the last date. On this single piece of evidence there is no reason for expecting repeated defoliation to be particularly harmful. However, in the absence of any data of this type in Britain the two experiments described here were undertaken.

The first was a small-plot clipping trial comparing the cumulative effect of three defoliations at 7-day intervals with single defoliations on each of these dates. The second was a field-scale experiment comparing continuous grazing with daily folding, in order to discover whether the grazing of fresh growth under continuous grazing conditions gave more serious reductions in grain yield than a rapid defoliation with no grazing of regrowth.

Experiment I

Methods

In the spring of 1954 this experiment was superimposed on a commercial crop of Cappelle Desprez wheat on Wye College Farm. The eight treatments used were the factorial combinations of three clipping dates, referred to throughout this paper as *A*, *B*, and *C*.

A 29 March 1954
B 5 April 1954
C 12 April 1954

These eight treatments were replicated six times in randomized blocks giving a total of forty-eight plots. Each plot was made up of seven drill rows 6 ft. long, and the wheat was clipped with scissors to within a $\frac{1}{2}$ in. of ground level on the appropriate dates. At harvest 1 square yard was cut from the centre of each plot, leaving a 1-in. stubble. The produce was threshed in a small electrically driven thresher and the ear number, 1,000-grain weight, and yield of grain and straw were determined.

Results

The amount of wheat leafage removed at each clipping is given in Table 1. The yield from the single-cut treatments *A*, *B*, and *C* can be used as a measure of growth in the uncut crop over this period. It will be seen from Table 1 that production almost doubled each week.

However, after clipping, growth was much reduced as shown in the lower part of Table 1. A single cut on either 24 March or 5 April had serious effects on production and the combined effect of these two clippings was even more drastic. Throughout April and May visual inspection of the plots showed that these trends were continued, growth being

less on the cut plots than on the controls, and much less where cutting had been done two or three times.

TABLE 1. *Yields of Wheat Leaf at Three Dates of Clipping. Expt. I (lb. D.M/acre)*

Treatment	*A* *1st cut* *29 March*	*B* *2nd cut* *5 April*	*C* *3rd cut* *12 April*	*Total yield*
A	245	..	..	245
B	..	433	..	433
C	..	..	798	798
AB	250	90	..	340
AC	237	..	245	482
BC	..	401	155	556
ABC	251	86	71	408

Estimated Wheat Leaf Production During Period 5–12 April

Not previously cut	381
Cut 29 March	157
Cut 5 April	155
Cut 29 March and 5 April	71

TABLE 2. *The Effect of Treatments on Length of Straw and on the Incidence of Lodging. Expt. I*

Treatment	*Length of straw (in.)*	*Area lodged (%)*
o	38·6	87
A	38·3	53
B	37·8	o
C	36·9	o
AB	38·5	o
AC	38·o	o
BC	37·7	o
ABC	36·9	o
Mean	37·8±o·34	
L.S.D. P = o·o5	1·o	
P = o·o1	1·3	
P = o·oo1	1·7	

During storms in early June some lodging took place and the percentage area of each treatment affected is given in Table 2. Lodging was confined to the two treatments which had had the most lenient cutting, which suggests that clipping was responsible for preventing lodging on all other treatments. The measurements of straw length also given in Table 2 show that treatments *C* and *ABC* gave highly significant reductions in length of straw; the slight reductions for the other treatments were not significant. Straw length is difficult to measure accurately in the standing crop, particularly when lodging has taken place. These results do, however, show a general trend for clipping to reduce straw length. It might therefore be expected to increase resistance to lodging.

TABLE 3. *The Effect of Treatments on Yield of Straw and on Number of Ears per Yard of Row. Expt. I*

Treatment	*Yield of straw (cwt./acre)*	*No. of ears/ yd. of row*
0	62·8	94·7
A	58·4	84·0
B	57·3	79·8
C	58·6	85·9
AB	58·5	79·0
AC	53·6	75·8
BC	50·9	74·9
ABC	49·5	67·9
Mean	56·2±1·92	80·2±2·70
L.S.D. P = 0·05	5·5	7·8
P = 0·01	7·4	10·4
P = 0·001	9·8	13·8

The yields of straw and the numbers of ears per yard of row (Table 3) were significantly reduced by clipping. The response to two and three clippings was a simple additive one, i.e. the total effect of two clippings was similar to the sum of their individual effects. This was confirmed by the absence of any significant interaction between cutting dates, and means that each individual cut on 12 April had a similar effect on straw yield and ear number independent of whether it was the first, second, or third cut. Reference to Table 1 shows, however, that very different amounts of leafage were removed by these cuts, depending on previous cutting treatment.

TABLE 4. *The Effect of Treatments on Grain Yield. Expt. I*

Treatment	*Grain Yield (cwt./acre)*
0	33·5
A	37·3
B	39·7
C	39·9
AB	38·2
AC	37·0
BC	34·6
ABC	31·1
Mean	36·4±1·5
L.S.D. P = 0·05	4·4
P = 0·01	5·9
P = 0·001	7·7

Interaction B×C (from analysis of variance)

Treatment	*0*	*B*	
0	35·4	38·9	37·2
C	38·5	32·9	35·7
	37·0	35·9	36·4

B×C significant at P = 0·001

The grain yields form a more complex picture (Table 4) since treatments *B*, *C*, and *AB* significantly increased yield above control but *BC* and *ABC* resulted in yields similar to control. The low yields from control and *A* are almost certainly attributable to the lodging previously mentioned, and conversely the improvements in yield due to moderate

clipping (*B*, *C*, and *AB*) were the result of improved resistance to lodging. However, intensive repeated cutting reduced yield in a similar fashion to the effect on straw (Table 3). It is noteworthy that the double-cut treatment *AB* had a smaller effect on grain and straw than the other double-cut treatments, probably because clipping was completed at a relatively early growth stage. The interaction $B \times C$ was highly significant for the grain yield: singly they produced high yields, but when

TABLE 5. *The Effect of Treatments on 1,000-grain weight. Expt. I*

Treatment	*1,000-grain wt. (gm.)*
0	43·5
A	45·8
B	47·6
C	46·5
AB	47·6
AC	47·1
BC	46·6
ABC	44·7
Mean	46·2±0·9
L.S.D. P = 0·05	2·5
P = 0·01	3·4
P = 0·001	4·4

Interaction $B \times C$ (from analysis of variance)

Treatment	*0*	*B*	
0	44·6	47·6	46·1
C	46·8	45·7	46·2
	45·7	46·7	46·2

$B \times C$ significant at P = 0·01

they were combined yields were reduced. The 1,000-grain weights (Table 5) showed very similar trends to the grain-yield results. 1,000-grain weight was reduced by lodging and by severe clipping and the $B \times C$ interaction was again highly significant. Therefore, in part, differences in yield are attributable to differences in grain size, but since the treatment had a greater effect on yield than on grain size, other components of yield also contributed to these yield differences.

Conclusions

Up to a certain point reductions in straw yield and length induced by clipping improved grain yields, due to the resistance to lodging thereby conferred. Beyond this point the reduction in growth was so great that grain yields were adversely affected. A single cut in April gave optimum grain yields, the control and March-clipped plots suffered from lodging and (with the exception of treatment *AB*) those plots cut more often than once suffered from the additive effect of successive defoliations. These general results, therefore, differ from those of Cutler *et al.* [3] in Indiana.

Experiment II

A field-scale experiment was carried out in 1956 to compare the effects of continuous grazing and fold grazing on a commercial crop of Banco wheat. A randomized block design with fivefold replication was used, each plot being 1,000 square yards in area. The continuous-grazing plots carried two sheep for 14 days (8–22 April) whilst on the fold-grazing treatment two sheep were systematically folded over an equivalent

area during the same period. An ungrazed treatment was included as a control.

Results

The mean yields of grain (Table 6) were remarkably similar, and there were no significant differences between treatment means for grain yield, ear number, or 1,000-grain weight, in spite of low coefficients of variation in each case. There was virtually no lodging with any of the treatments. These results were unusual in that grazing had no appreciable effect on yield or lodging. This absence of response to grazing may have been due in part to the cold late spring in 1956, and in part to Banco being a late-maturing variety of wheat. It is quite clear that the conditions under which this single experiment was conducted were abnormal and that before any definite conclusions can be drawn it should be repeated over more than one season. Due to other commitments it was impracticable to continue this work at Wye, but it was deemed worth while to put these results on record.

TABLE 6. *The Effect of Treatments on Grain Yield, Ear Number, and 1000-grain Weight. Expt. II*

	Control	*Fold grazing*	*Continuous grazing*	*Mean*
Yield of grain (cwt./acre) . .	37·0	37·1	36·7	36·9±0·67
No. of ears/yd. of row . .	74·5	78·1	72·9	75·2±1·38
1,000-grain weight (gm.) . .	36·5	36·5	37·2	36·7±0·36

All differences between means were non-significant.

Discussion

The general response of Cappelle Desprez wheat to clipping in Experiment I was in full agreement with the three general conclusions outlined at the beginning of this paper. Grain yields were improved up to the point where lodging took place, and beyond that point yields were reduced. It was generally true that the later the clipping the more significant was the effect on yield. The original contribution of this work is the evidence produced on multiple clippings. A second or third clipping at 7-day intervals gave quite small yields of herbage but gave further reductions in yield of grain and straw similar to those resulting from the initial cut. The small amount of dry matter obtained from these second and third cuts involved disproportionate losses of grain and straw and could therefore be justified only where serious lodging was expected and a means of markedly checking the crop was required. This pronounced cumulative effect of two or more cuts was not found in the results of Cutler *et al.* [3] in the U.S.A. Since repeated clipping of fresh growth had an adverse effect on yield, it was considered that this effect might occur under continuous-grazing management, but Experiment II comparing continuous grazing with folding was inconclusive in that no lodging occurred and no difference between treatment yields was significant.

The conditions of this experiment were abnormal and before any general conclusions can be drawn on the effects of these grazing treatments the experiment would have to be carried out over several seasons.

The practical implications of this work are that a return to sheep folding is not to be recommended. Folding is merely a convenient experimental method of producing a dense stocking for a short period in contrast to a prolonged period of low-density stocking which may be found in continuous grazing. The fundamental comparison is between densities of stocking, rather than between continuous grazing and folding. If concentrated, short-duration stocking were to be shown to be the most efficient method it would become a general principle of cereal grazing, the detailed application of which must be adapted to particular circumstances. However, this has not been established by the field-scale experiment, and at this stage the only practical recommendation arising from this work is that a second or third clipping has harmful effects on the yield and growth of wheat out of all proportion to the extra leafage removed.

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BREEDING EFFICIENCY OF EGYPTIAN COWS AND BUFFALOES

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Summary

A study has been made of some of the factors that influence breeding efficiency in Egyptian cows and buffaloes. The average number of services per conception was found to be 1·9 in cows and 2·1 in buffaloes. Estimates of repeatability of this value were very low and statistically insignificant.

Sequence of calving indicated that virgin heifers, irrespective of the sire's age, needed more services than older ones, for both species of animals. Such averages decreased after the first calving up to the third in cows and the fourth in buffaloes, after which there was a tendency for the number to increase again.

Age affected greatly the average number of services per conception in both groups of animals; young females (other than virgin heifers) mated to young bulls required fewer services than old females mated to old bulls.

The identity of the sire affected the average number of services per conception. In cows the highest average was found to be 2·5 and the lowest 1·1 services, while for buffaloes the range was 3·1 to 1·8.

Correlation coefficients between the length of service period and the average number of services per conception indicated no relationship between these two characters, the correlation coefficients being statistically insignificant.

Season of the year influenced greatly the average number of services per conception in both species; it was found to be higher during summer months.

There was a year-to-year variation; the lowest numbers of services per conception were 1·5 and 1·3, and the highest 2·4 and 2·9 in cows and buffaloes respectively.

INVESTIGATIONS concerning breeding efficiency of dairy cattle, which is an important economic character, are needed in regulating the production of the herd to meet market requirements. Therefore, a successful dairy herd depends not only upon the quality and quantity of milk but also on the ability to calve at regular periods. In such an ideal herd, females should give a larger total milk yield than that obtained when parturition occurs at longer intervals.

The present work was undertaken in order to study the effects of some of the various factors that influence breeding efficiency of Egyptian cows and buffaloes. These factors are: sequence of calving; age of parents; effect of sire; service period; season of year; and year.

Materials and Methods

The records of the dairy herd kept at the University Farm have been analysed to determine the relationship of some of the factors that affect the breeding efficiency of dams and sires. The data used cover the period 1942 to 1956 inclusive.

Management and feeding of such a herd have been reported by Tantawy and Ahmed [1] who also studied other economic characters of this herd [2, 3, 4, 5]. Efforts have been made to keep the management of the herd as uniform as possible with special care to the sires.

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Results and Discussion

In a selection programme for dairy cattle attention should be paid to the more highly fertile individuals, i.e. productive efficiency. It is important to regulate calving in such a way as to attain the largest milk production. Therefore, it is of interest to investigate the genetic and environmental factors that influence the number of services per conception.

The repeatability of the value for number of services per conception in cows and buffaloes respectively was found to be $0{\cdot}01 \pm 0{\cdot}02$ and $0{\cdot}06 \pm 0{\cdot}04$. Both values are very low and statistically insignificant, which suggests that transmissible hereditary differences are not the basis of the intra-cow repeatability.

These results agree with those reported by Ragab *et al.* [6] for Egyptian cows (0·002) but not with those for buffaloes (0·308). Our results thus agree with those found on foreign breeds of cattle by several workers [7, 8, 9, 10, 11]. Berge [12] found a significant intra-cow repeatability of the value for number of services per conception in Norwegian cattle.

Factors affecting Breeding Efficiency

Sequence of calving. Table 1 shows the average number of services per conception, in cows and buffaloes, in different calving sequences. The results suggest that in both species dams giving birth to males require more services than those giving birth to females, though the differences are not significant. Buffaloes appear to need more services per conception than cows, the averages being 1·9 and 2·1 respectively.

It can also be seen that the average number of services per conception was high at the first calving, then it decreased up to the fourth calving in cows and to the fifth in buffaloes, after which there was a tendency for the averages to increase.

These results, especially with buffaloes, do not entirely agree with those reported by Ragab *et al.* [6] on another herd of Egyptian buffaloes and cows. They reported that the average number of services decreased, in both groups, until the third calving, after which it increased again.

In foreign breeds of dairy cattle where all services are recorded, the number of services per conception ranged between 1·7 and 2·9, as reported by many investigators [13, 14, 15, 16, 17, 18].

Age of parents. Tables 2 and 3 show the effects of dam's age on breeding efficiency of both cows and buffaloes. These tables demonstrate that virgin heifers of both species required more services to conceive than older females. The average number of services per conception declined up to the age of 6–7 years in cows and 8–10 years in buffaloes and increased thereafter.

In foreign breeds of cattle, Morgan and Davis [15] reported that virgin heifers required more services than were needed at any subsequent calving up to the tenth. The same conclusion has been reported by other workers [13, 16, 17, 18, 19], while Knoop and Hyden [20] found that sequence of calving had no effect.

Tables 2 and 3 also indicate that about 47 per cent. of the total females, both cows and buffaloes, needed only one service to conceive, while less

TABLE 1. *Effects of Sequence of Calving, in Cows and Buffaloes, on Breeding Efficiency*

Sequence of calving	*Cows*					*Buffaloes*				
			Number of services per conception					*Number of services per conception*		
	Total no. of services	*Total conception*	*Males*	*Females*	*Mean for both sexes*	*Total no. of services*	*Total conception*	*Males*	*Females*	*Mean for both sexes*
1st	143	68	2·2±0·1	1·9±0·3	2·1	182	70	2·5±0·3	2·8±0·4	2·6
2nd	99	58	1·7±0·2	1·7±0·1	1·7	133	58	2·4±0·3	2·2±0·2	2·3
3rd	60	36	1·8±0·3	1·6±0·2	1·7	82	42	2·1±0·3	1·6±0·5	1·9
4th	49	29	1·4±0·2	2·0±0·2	1·7	56	27	1·9±0·4	2·2±0·4	2·1
5th	29	14	2·5±0·3	1·8±0·3	2·1	36	20	1·9±0·2	1·8±0·4	1·8
6th and over . . .	130	68	2·0±0·3	1·8±0·2	1·9	194	103	2·0±0·2	1·8±0·2	1·9
Total or average . .	510	273	1·9±0·2	1·8±0·2	1·9	683	320	2·1±0·3	2·0±0·3	2·1

than one-third needed two services. These results, for buffaloes, do not differ significantly from those reported by Hafez [21].

The percentage of aborted calves was about 6 and 8 in cows and buffaloes respectively, with a higher incidence when females were about 7–8 years old. Tantawy and Ahmed [3] stated that abortion took place

TABLE 2. *Effects of Dam's Age on Breeding Efficiency in Cows*

Dam's age (years)	*Total no. of services*	*Total no. of conceptions*	*Conceptions as % of no. of services*				*Aborted calves %*	*Average no. of services per conception*
			1	*2*	*3*	*4 and over*		
3·1±0·2	139	66	43·9	28·8	15·2	12·1	8·8	2·1±0·2
4·1±0·1	114	62	54·8	29·0	6·5	9·7	2·8	1·8±0·2
5·4±0·1	60	36	61·1	22·2	11·1	5·6	9·8	1·7±0·2
6·4±0·1	47	30	66·7	16·7	10·0	6·6	2·9	1·6±0·2
7·7±0·1	33	18	44·4	33·3	16·7	5·6	14·7	1·8±0·3
9·0±0·2	28	15	46·7	33·3	13·3	6·7	5·9	1·9±0·3
10·0±0·2	24	13	46·1	38·5	7·7	7·7	5·9	1·9±0·2
11·2±0·2	36	16	31·3	43·7	12·5	12·5	..	2·3±0·3
12·4±0·2	30	14	35·7	35·8	7·1	21·4	5·6	2·1±0·2
13·0±0·3 and over	30	17	41·2	41·2	17·6	..	..	1·8±0·2
Total or average	541	287	47·2	32·2	11·8	8·8	5·6	1·9±0·2

TABLE 3. *Effects of Dam's Age on Breeding Efficiency in Buffaloes*

Dam's age (years)	*Total no. of services*	*Total no. of conceptions*	*Conceptions as % of no. of services*				*Aborted calves %*	*Average no. of services per conception*
			1	*2*	*3*	*4 and over*		
3·5±0·1	183	70	37·1	17·2	20·0	25·7	2·9	2·6±0·3
5·0±0·1	143	60	36·7	28·3	11·7	23·3	1·7	2·4±0·3
6·4±0·2	84	43	53·5	23·2	7·0	16·3	6·8	2·0±0·3
7·5±0·2	61	29	37·9	37·9	10·4	13·8	7·1	2·1±0·4
8·6±0·2	39	21	42·8	38·1	14·3	4·8	22·7	1·9±0·2
9·5±0·2	42	25	56·0	28·0	12·0	4·0	3·8	1·7±0·3
11·3±0·3	50	25	48·0	28·0	8·0	16·0	4·0	2·0±0·4
12·4±0·2	30	19	57·9	31·5	5·3	5·3	5·3	1·6±0·4
13·4±0·3	29	17	64·7	23·5	5·9	5·9	11·8	1·7±0·3
14·7±0·3 and over	43	21	33·3	38·1	19·1	9·5	14·3	2·1±0·3
Total or averages	704	330	46·8	29·4	11·4	12·4	8·1	2·0±0·3

in Egyptian cows and buffaloes when the foetus was about seven months old, while Hafez [22] reported that abortion in buffaloes was common during the third and fourth month of pregnancy.

It is also shown in Tables 2 and 3 that the percentage of abortions had no effect on the average number of services per conception during the following season. Such results are contrary to those reported by Hafez [21] who found that aborted animals required more services per conception than normally calving ones.

Table 4 shows the effects of the sire's age on the breeding efficiency, in the two species, as indicated by the average number of services per conception. The results indicate that the average number of services per conception showed a higher value for sires of 2–3 years old, then decreased up to the age of 4–5 years, when they tended to increase again. Hilder *et al.* [17] found that age of sire had an effect on the breeding efficiency in Friesian cattle.

TABLE 4. *Effects of Sire's Age on Breeding Efficiency in Cows and Buffaloes*

	Cows			*Buffaloes*		
Age of sire (years)	*Total no. of services*	*Total no. of conceptions*	*Average no. of services per conception*	*Total no. of services*	*Total no. of conceptions*	*Average no. of services per conception*
2–3	22	11	2·0±0·2	36	15	2·4±0·2
3–4	58	35	1·7±0·2	70	41	1·7±0·2
4–5	110	64	1·7±0·2	158	79	2·0±0·2
5–6	88	48	1·8±0·2	158	74	2·1±0·3
6–7	84	44	1·9±0·3	97	39	2·5±0·3
7–8	87	42	2·1±0·3	54	22	2·5±0·3
8–9	34	18	1·9±0·2	52	14	3·7±0·3
10 and over	91	40	2·7±0·3	114	37	2·7±0·3
Total or average	574	302	2·0±0·2	739	321	2·4±0·3

A study of the effects of young and old bulls, when bred to females of different ages, on the breeding efficiency was carried out; the results are set out in Table 5. Females were grouped according to their calving sequences, those bred to more than one sire in their calving sequence being omitted.

The results indicate that young bulls were more efficient than older ones. The least number of services per conception is found in the two groups of young bulls when dams are about 5 to 8 years old (or at their 3rd to 5th calving) in cows and buffaloes respectively. It is of interest to note that females of different ages mated to young bulls needed 1·7 and 2·0 services per conception, while when bred to older sires these values rose to 2·3 and 2·2 in cows and buffaloes respectively.

These results agree with those given by Hilder *et al.* [17] on Friesian cattle, who reported that the average for young bulls was 1·9 services per conception while that for older ones was 2·5.

In the present study fourteen and eight sires, for cows and buffaloes respectively, were used, and the breeding efficiency of each is presented in Table 6. The results indicate that there were significant differences between the fertility of the various sires in each species. For the cows, sire No. 7, and for the buffaloes, sire No. 1, showed the least number of services per conception, about 1·1 and 1·7 respectively, while sires No. 10 and 8 showed the highest values: about 2·5 and 3·1 respectively.

Miller and Grave [24] found that the average number of services per conception was 2·5, and the best bull used required 1·55 services, while

TABLE 5. *Effects of Age of Both Parents on Breeding Efficiency in Cows and Buffaloes*

Dam's sequence of calving	*Bulls 2–5 years old*			*Bulls 6 years old and over*		
	No. of services	*No. of conceptions*	*Average no. of services per conception*	*No. of services*	*No. of conceptions*	*Average no. of services per conception*
Cows						
1	60	33	1·8±0·3	77	34	2·3±0·3
2	42	25	1·7±0·2	68	39	1·7±0·2
3	39	26	1·5±0·2	37	17	2·1±0·3
4	40	22	1·8±0·3	13	11	1·2±0·2
5	14	12	1·2±0·2	22	10	2·2±0·3
6	15	10	1·5±0·2	15	6	2·5±0·2
7	10	6	1·7±0·2	6	4	1·5±0·2
8	17	8	2·1±0·3	15	6	2·5±0·2
9	12	6	2·0±0·3	21	5	4·2±0·4
10 and over	21	11	1·9±0·3	9	4	2·3±0·3
Total or average	270	159	1·70	283	136	2·08
Buffaloes						
1	96	43	2·2±0·3	129	42	3·1±0·4
2	57	34	1·7±0·3	107	44	2·4±0·3
3	41	25	1·6±0·3	62	29	2·1±0·3
4	35	17	2·1±0·3	57	24	2·4±0·3
5	23	15	1·5±0·3	57	24	2·4±0·3
6	35	18	1·9±0·2	38	20	1·9±0·3
7	37	18	2·1±0·2	49	23	2·1±0·4
8	14	9	1·6±0·2	25	14	1·8±0·2
9	30	12	2·5±0·3	32	14	2·3±0·3
10 and over	34	12	2·8±0·3	47	21	2·2±0·3
Total or average	402	203	1·98	603	255	2·37

TABLE 6. *Effects of Individual Sires on Breeding Efficiency in Cows and Buffaloes*

Sire no.	*Cows*				*Buffaloes*			
	% of progeny in the herd	*Total no. of services*	*Total no. of conceptions*	*Average no. of services per conception*	*% of progeny in the herd*	*Total no. of services*	*Total no. of conceptions*	*Average no. of services per conception*
1	21·1	23	14	1·6±0·2	36·8	193	108	1·7±0·3
2	8·2	35	25	1·4±0·2	16·0	95	46	2·1±0·3
3	6·9	24	19	1·3±0·2	6·6	42	19	2·2±0·3
4	17·1	82	50	1·6±0·3	3·1	17	9	1·9±0·3
5	2·6	10	8	1·3±0·2	6·6	39	18	2·2±0·3
6	5·3	31	16	1·9±0·3	15·6	91	45	2·0±0·3
7	2·6	10	9	1·1±0·2	11·2	96	32	3·0±0·3
8	2·6	16	8	2·0±0·3	4·2	36	12	3·1±0·4
9	3·3	25	10	2·5±0·2				
10	7·6	76	30	2·5±0·2				
11	10·5	60	31	1·9±0·2				
12	2·6	19	9	2·1±0·2				
13	6·0	13	6	2·2±0·2				
14	3·6	9	5	1·8±0·2				

Walton *et al.* [25] stated that a service record of 1·1 had been obtained for an exceptional male.

Effects of service period. The effects of service period, i.e. the period elapsed between parturition and the next fertile service, on the average

TABLE 7. *Effects of Service Period on Breeding Efficiency in Cows and Buffaloes*

Sequence of calving	*Cows*				*Buffaloes*			
	No.	*Average service period (days)*	*Average no. of services per conception*	*Time from parturition to first service, days*	*No.*	*Average service period (days)*	*Average no. of services per conception*	*Time from parturition to first service, days*
2nd	64	143·9±11·9	1·7±0·1	76·8± 8·9	61	179·9±17·6	2·3±0·2	108·3±10·5
3rd	44	112·8±11·1	1·7±0·2	81·8± 9·1	43	158·5±14·9	1·9±0·2	104·5± 9·6
4th	30	107·5±11·6	1·7±0·2	75·8±10·2	34	162·1±16·0	2·1±0·3	99·9± 8·9
5th	21	120·6±12·5	2·0±0·3	74·9± 9·1	53	173·9±22·0	2·0±0·3	99·8± 9·3
6th and over . .	74	126·7±12·9	2·0±0·2	88·5± 9·7	99	168·4±18·0	1·9±0·3	96·2± 7·9
Total or average .	233	122·3±12·0	1·8±0·2	79·8± 7·5	290	168·6±17·7	2·1±0·3	101·5± 9·2

number of services per conception, in cows and buffaloes, are presented in Table 7. The first service took place on the average after 79·8 and 101·5 days from parturition in cows and buffaloes respectively. The averages for the service periods in cows and buffaloes were about 122 and 169 days, respectively. These results do not differ significantly from those reported by Ragab *et al.* [6] for another herd of Egyptian cows and buffaloes, though the average number of services per conception was different. Sikka [26] found a similar average service period, in Friesian cattle, to that reported in the present study for cows, while Edwards [27] obtained different results in Jersey cattle. Alim and Ahmed [28] reported a 283-day service period in a large commercial herd of Egyptian buffaloes, which differs significantly from that in the present work.

Table 7 also indicates that cows showed a shorter service period and needed fewer services per conception than buffaloes. Such results agree with those reported by Ragab *et al.* [6] for cows but not for buffaloes. The latter difference could be explained on the basis of the higher percentage of silent heat in buffaloes, as noticed by Hafez [22 and 23].

The correlation coefficients between the service period and the number of services per conception in both cows and buffaloes were low and insignificant, viz. for 215 cows 0·01 ± 0·1, for 235 buffaloes 0·004 ± 0·01.

Effects of season of year. In order to determine whether the season of the year has any effects on breeding efficiency, the services required per conception are compiled by months and presented in Table 8, which

TABLE 8. *Effect of Month on Breeding Efficiency in Cows and Buffaloes*

	Cows				*Buffaloes*			
Month	*Total no. of services*	*Total conceptions*	*% aborted calves*	*Average no. of services per conception*	*Total no. of services*	*Total conceptions*	*% aborted calves*	*Average no. of services per conception*
January	106	55	..	1·9 ± 0·2	83	36	..	2·3 ± 0·3
February	47	25	..	1·9 ± 0·2	66	38	..	1·7 ± 0·3
March	40	19	..	2·1 ± 0·3	90	47	2·1	1·9 ± 0·2
April	24	7	..	3·5 ± 0·4	59	25	..	2·4 ± 0·4
May	24	10	..	2·5 ± 0·3	15	10	20·0	1·5 ± 0·3
June	16	7	12·5	2·3 ± 0·3	52	18	15·8	2·9 ± 0·3
July	27	11	31·2	2·5 ± 0·3	28	10	20·0	2·8 ± 0·3
August	28	10	14·3	2·8 ± 0·3	52	22	8·6	2·4 ± 0·3
September	31	27	4·9	1·2 ± 0·2	76	36	13·9	2·1 ± 0·3
October	61	39	11·1	1·6 ± 0·2	75	37	10·8	2·0 ± 0·3
November	53	34	..	1·6 ± 0·2	69	27	10·8	2·6 ± 0·3
December	73	41	..	1·8 ± 0·3	66	39	5·1	1·7 ± 0·3
Total or average	530	285	6·2	2·1 ± 0·3	731	345	8·9	2·2 ± 0·3

shows an increase in the average number of services per conception during the months of April to August in cows, while in buffaloes no definite trend is shown, though a marked increase in the number of services required for conception appears during the months of June to August inclusive.

These results are in agreement with those reported by Hilder *et al.*

[17] who found an increase in the number of services per conception in Friesian cattle during summer time.

The period of the lower fertility during the summer, in the present study, may be attributed to the higher temperature as well as the scarcity of green fodder which may have a detrimental physiological effect on the animal. Phillips *et al.* [29], studying seasonal variation in bull semen, reported that most measures of quality in semen indicate that it is of lower quality during the summer months than during the rest of the year.

Effect of year. Table 9 shows the variation in breeding efficiency from year to year in both cows and buffaloes.

TABLE 9. *Effect of Year on Breeding Efficiency in Cows and Buffaloes*

	Cows				*Buffaloes*			
Year	*Total no. of services*	*Total conceptions*	*% aborted calves*	*Average no. of services per conception*	*Total no. of services*	*Total conceptions*	*% aborted calves*	*Average no. of services per conception*
1942–4 . .	66	45	..	1·5±0·2	27	21	14·3	1·3±0·2
1945–6 . .	80	54	29·1	1·9±0·2	77	53	15·1	1·5±0·2
1947–8 . .	69	43	5·5	1·6±0·3	69	41	7·3	1·7±0·3
1949–50 .	88	44	4·4	2·0±0·3	103	44	9·1	2·3±0·3
1951–2 . .	107	46	2·0	2·3±0·3	115	51	5·9	2·3±0·3
1953–4 . .	72	36	..	2·0±0·2	136	55	3·6	2·5±0·4
1955–6 . .	59	29	..	2·4±0·2	129	45	..	2·9±0·4
Total or average	541	293	5·9	1·9±0·3	656	310	7·9	2·1±0·3

It seems that there is a tendency for the number of services required per conception to increase from the year 1949 in both species of animals. This could be explained only on the basis of sire's age as other environmental factors were almost constant. Such decrease in breeding efficiency is very obvious in buffaloes, since a certain sire has been used up till now and mated to a large number of females in the herd, as indicated by the percentage of progeny, see Table 7.

The high percentage of abortion appearing in the years 1945 and 1946 was due to a heavy attack of foot and mouth disease. It is evident that there is no tendency for the number of services per conception to increase due to the occurrence of high percentage of abortion.

Hilder *et al.* [17] stated that there was a tendency for the fertility to be low in the years following those in which greatest percentage of abortion occurred. While Miller *et al.* [24] found that fertility decreased after abortions caused by brucellosis but not after abortions that resulted from other causes.

Conclusions

This analysis of the breeding records of a dairy herd of Egyptian cows and buffaloes, covering a period of fifteen years, in which the data for 287 cows and 330 buffaloes were examined, thus shows that 47 per cent. were conceived at the first service. It also indicates that almost all the females may eventually conceive if served a sufficient number of times. The average number of services per conception was found to be 1·9 and 2·1 in cows and buffaloes respectively.

The low repeatability of the value for number of services required for successive conceptions of the same female, in both species, indicates that the variation of reproductive efficiency is due to non-genetic factors. Heritability estimates should give a better basis for such a conclusion, but the present data are not sufficient for such estimation. However, various workers on foreign breeds of cattle have shown that the heritability of such character is very low [7, 9, and 11]. Therefore, provided conception does take place, a female should not be culled from the herd merely on the grounds that more than a single service is required.

The insignificant correlation between service period and the number of services required indicates that fertility could be measured only on the basis of either expected number of services or the length of service period, because of the occurrence of silent heat in cattle [25] and especially in buffaloes [21].

The present study indicates clearly that the average number of services required per conception in both species of animals are liable to be influenced by many factors, of which the most important are: sequence of calving, age, and season of the year.

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THE EFFECT OF SPACING ON THE ENVIRONMENT AND PERFORMANCE OF CACAO UNDER NIGERIAN CONDITIONS. I. AGRONOMY

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Summary

An experiment designed to compare the effects of seven spacings on the growth and performance of Trinitario and Amelonado cacao types was carried out near Ibadan, Nigeria, on typical good cacao soil, during the period 1941–56. Although the results are obscured by heavy capsid infestation and a serious defect in the design, the following conclusions can be drawn:

Density of stand profoundly affected establishment, ease of management, early yields, health, and performance.

Differences in vigour and behaviour between Amelonado and Trinitario were noted. The optimum tree density for Amelonado type was found to be about 800 per acre, while Trinitario required at least 1,000 per acre for optimum yields. The minimum density required for economic yields appears to be about 580 per acre.

The average number of pods and the average weight of wet beans per tree increased with the decreasing stand density but not sufficiently to increase the yield per acre at lower densities.

THE present paper records results obtained from a cacao spacing trial during 1942–56 and the effect of density of planting on the establishment and performance of mature cacao. It is an account supplementary to that given by Russell [1] which covers the initial period 1942–52; and is intended to form a basis for a subsequent paper dealing with the effect of tree density on soil nitrate, soil-moisture fluctuations, and microclimatic conditions under cacao.

Experimental

The investigation was conducted at the Government Cocoa Experimental Farm 'Ina.' and was originated by the Botany Section of the Agricultural Department Nigeria. Recently (1955) it was taken over by the Western Region Department of Agriculture.

The farm is some 13 miles south of Ibadan and approximately 400 feet above sea level in N. lat. 7° 13′, E. long. 3° 52′. The average annual rainfall for the period under review was 49·2 in. with 106 days measurable precipitation per annum. The rainy season lasts usually from April to November, with two rainfall maxima, May/June and September/October (August being relatively dry) and is accompanied by high humidity. There is approximately a four-month dry season of varying intensity, lasting from November/December to February/March.

The district is gently undulating, covered for the greater part with secondary forest and occasional remnants of high forest.

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Geologically the district forms part of the basement complex consisting of crystalline metamorphic rocks, originally sedimentary and igneous, of pre-Cambrian age. The farm itself is on a fine-grained biotite gneiss decomposed to considerable depth.

The soils of the experimental area are identified as Olorunda Series and Egbeda-Olorunda/Iregun transition soils. The profiles of these soils are noticeably browner in colour than typical examples of the same series nearby. This difference is probably associated with a high percentage of basic minerals in the parent gneiss. These profiles have been described by Vine *et al.* [2].

The soil under undisturbed forest conditions is characterized by a high content of surface organic litter with numerous earthworm casts which in some places are 1 in. or more thick. The surface layer is very crumbly and loose. This characteristic, however, is rapidly lost if land is put under cacao or cultivation.

Treatments

The treatments comprise seven spacings, tabulated in Table 1, and two cacao types, Amelonado and Trinitario (selection T. 38).

The actual stand density in 1956 is much lower than the original (see Table 1).

The object of the experiment is to evaluate the difference in yield between the two cacao selections and their performance at seven spacings.

Layout

The experiment consists of a 7×7 latin square, planted with the two types of cacao in alternate rows. The plots are of uniform size (60×60 ft.) or about $\frac{1}{12}$ acre, separated by single guard rows. Arrangement of the two cacao selections in alternate rows, rather than on the split-plot basis, constitutes a serious defect in the design. The two selections differ markedly in vigour and in their response to treatments. It is to be expected that competition between the two types of cacao, of different vigour, grown in alternate rows, has affected the results, so far as the comparison of the two types is concerned. This design does not allow a direct measurement of yields per unit area of each cacao type.

Establishment

The experiment was started in 1941 with clear-felling of secondary forest. The large tree-trunks were removed off the site, but most of the remaining vegetation was left on the site as a mulch. A semi-permanent shade (Gliricidia) spaced at 10×10 ft. together with bananas spaced at 20×20 ft., were planted on all plots. The cacao seedlings were planted during the following year (May–June 1942). Each seedling was heavily mulched using green material from weeding. The establishment was fair; the loss of seedlings during the period 1942–6 averaged about 6 per cent. per dry season. Supplying of missing plants was carried out annually in May, and was usually followed by heavy mulching on all plots.

Girth measurements made in 1945 showed that cacao at the close spacing made better progress than that at the wider spacings. A number of trees at close spacings had produced flowers but no pods.

In 1946 most of the trees flowered, but only the close spacings produced a few pods. It was not until 1947 (the sixth year after planting) that all plots produced pods, and the yield recording started. The cacao at 5×5 ft. and 6×6 ft. spacings had formed a closed canopy by 1948, and all planted shade trees in these two treatments were removed, while on the remaining plots they were drastically reduced.

General Observations

Eight years after planting the canopies on all spacings had fully developed. Differences in habit of growth, and environment, had become pronounced. The close spacing produced a closed canopy, unbranched stems, and a ground surface clear of weeds and covered with a carpet of fallen leaves. The differences in tree height between spacings also became pronounced: close spacings produced higher trees. The wide spacings (15×15 ft. and 12×12 ft.) produced an open canopy, branching trees, and weedy ground surface.

Results and Discussion

Yields

The yield level on all plots, irrespective of treatments, is rather low, averaging 1,850 pods per acre per annum for the period 1948/9 to 1955/6, which is roughly equivalent to 160 lb. of dry cocoa per acre. The highest yield was obtained on the closest spacing during the 1952/3 season, amounting to 6,100 pods per acre, or roughly equivalent to 510 lb. dry cocoa per acre. Seasonal effects were very pronounced throughout the experimental period. The maximum yields on all plots were reached during the eleventh year (the fifth year of recording). During the following years, yields were maintained at a lower but more or less constant level.

It was thought that the yield of cocoa was probably affected by the heavy capsid infestation, which was allowed to thrive unchecked until the 1954 season. During that year routine anti-capside spraying with D.D.T. was started, and the recovery of the trees was spectacular and rapid. Surprisingly, however, this had no apparent effect on the yields.

Disease

It is unfortunate that no records of the incidence of *Phytophthora palmivora* (which causes Black Pod disease of cacao) are available as they would have improved the accuracy of the experiment and would in themselves provide valuable information. Most of the results described in this paper are based on pod numbers, the value of which is obviously affected by the lack of precise information regarding diseased pods.

Establishment in relation to type and spacing

As shown in Table 1, establishment and survival of Trinitario was persistently better than that of Amelonado cacao, in the ratio of 74 to 61, in spite of the efforts in management to attain a full stand for both types.

There is no significant relationship between stand density and percentage survival.

TABLE 1. *Surviving Stand per Acre in 1956*

Treatment (original spacing, ft.)	*Original stand per acre*	*Existing stand per acre*	*Percentage survival*			*Percentage of capsid-affected trees*
			T+A	*T*	*A*	
5×5	1,742	1,020	58·5	60	57	6
6×6	1,210	795	63·0	75	51	14
6×7½	968	683	70·0	73	67	24
7½×7½	772	577	70·0	90	50	68
10×10	435	268	60·0	65	55	84
12×12	302	221	72·5	74	71	92
15×15	193	154	78·0	81	75	100
Average			68	74	61	

T = Trinitario. A = Amelonado. In determining 'existing stand', trees of bearing size are distinguished from trees which are making little or no contribution to the yield.

Effect of Capsid Infestation on Cacao Establishment in Relation to Spacing

It has been generally accepted that the reaction of trees to capsid damage is most acute when they are growing at wide spacing, or lacking sufficient shade. The artificial shade conditions during the initial period of establishment (1942–8) were fairly uniform throughout the experiment. No records of the degree of capsid infestation are available for this period, but it is very unlikely that there were any differences between the treatments. With the formation of a closed cacao canopy in 1949 and with the removal of the temporary shade, the differences in shade conditions, between the various treatments, became pronounced, and it is very likely that the degree of capsid infestation then became related to treatments.

Assessment of capsid damage was first made in October 1956, by counting the number of trees in each plot which showed damage, no matter how slight. This showed that capsid infestation was clearly related to the planting density (see Table 1).

Effect of Spacing on the Time of Coming into Bearing

Table 2 shows that, on the average, trees at close spacing started to bear earlier than those at the wide spacings. In general, there appears to be a progressive delay in coming into bearing and maturity of performance with the decreasing tree density, to which attention has already been drawn by Russell [1]. This might be directly connected

TABLE 2. *Number of Pods per Acre at Actual Stand*

Actual stand/acre		*1,020*			*795*			*683*			*577*			*268*			*221*			*154*		
Selection		*T*	*A*	*T+A*	*T*	*A*	*T+A*	*T*	*A*	*T+A*	*T*	*A*	*T+A*	*T*	*A*	*T+A*	*T*	*A*	*T+A*	*T*	*A*	*T+A*
Season	*Year*																					
1947/8	(6)	..	..	85	..	..	40	..	..	76	..	..	21	..	..	5	..	..	36	..	..	19
1948/9	(7)	755	1,598	1,249	383	1,465	878	507	1,061	888	206	353	300	98	175	156	71	255	156	45	44	71
1949/50	(8)	653	1,071	823	913	1,638	1,203	680	988	797	149	204	162	27	82	43	23	22	22	11	0	9
1950/1	(9)	1,430	3,621	2,320	1,869	4,875	2,809	1,592	378	2,426	985	1,921	1,215	393	746	498	235	371	289	156	151	156
1951/2	(10)	3,620	4,985	4,171	3,298	7,116	4,493	4,137	6,935	5,196	3,029	708	4,009	541	1,666	696	731	950	817	403	455	415
1952/3	(11)	5,677	6,715	6,097	4,511	9,258	5,997	5,079	7,194	5,882	3,936	9,436	5,294	188	1,608	1,313	1,411	1,795	1,567	1,203	975	1,149
1953/4	(12)	3,127	3,306	2,199	2,551	6,134	3,673	1,530	3,110	430	1,542	41,16	2,211	551	1,566	704	459	632	528	142	609	405
1954/5	(13)	3,007	2,265	2,704	2,481	3,743	2,876	1,859	2,190	1,985	2,932	4,454	3,159	1,564	1,538	1,557	1,516	2,250	1,806	1,089	704	983
1955/6	(14)	3,121	2,277	2,777	2,005	2,534	2,170	1,871	2,008	1,923	1,946	2,892	2,182	880	915	891	1,283	1,273	1,282	847	521	770
Total		21,390	25,838	23,425	18,011	36,986	24,139	17,256	27,269	21,303	14,525	24,056	18,553	5,242	7,696	5,863	5,729	7,518	6,505	3,896	3,459	3,977
Average		2,673	3,229	2,602	2,251	4,623	2,682	2,157	3,408	2,367	1,815	3,007	2,061	655	962	651	716	940	723	487	432	442
Av. no. of pods per bearing tree		2·6	3·2	2·6	2·8	5·8	3·4	3·2	5·0	3·5	3·1	5·2	3·6	2·4	3·6	2·4	3·2	4·3	3·3	3·2	2·8	2·9

Yield of Wet Beans per Acre in lb. (T+A)

1948/9	230	152	149	54	33	12
1949/50	163	247	170	36	10	5	2
1950/1	483	519	429	234	88	55	31
1951/2	832	872	1,048	796	142	171	92
1952/3	1,339	1,278	1,218	1,126	266	334	237
1953/4	734	799	483	476	150	118	85
1954/5	548	585	424	581	273	325	199
1955/6	403	420	389	408	166	199	133

T = Trinitario selection. A = Amelonado selection

with the differences in the light intensity, since Evans and Murray [3] found that, under Trinidad conditions, flowering and fruit setting occurred earlier at light intensities of 50 per cent. and lower, and was much reduced at higher intensities.

Difference in Yield Performance between Trinitario and Amelonado Selections in Relation to Spacing and Seasons

Table 2 shows that there was a marked difference in vigour and in the response of the two cacao selections towards treatments. Amelonado cacao gave persistently higher yields per acre over the years, and at all spacings except the widest, where T. 38 gave a slightly better performance. The overall difference, in yield of pods per acre, between the two selections was about 28 per cent. in favour of Amelonado.

Relationship between Density of Stand and Crop Performance

The effect of stand on the yield of cocoa, measured as number of pods and weight of wet beans per acre (but not as number of pods per tree), is directly proportional to the density of stand, within certain limits (Table 2).

There is an obvious and important difference between the two cacao types in their yield performance in relation to spacing. For the Trinitario selection the relationship is linear throughout the whole range of tree densities under test and fits fairly well the values obtained from the regression function. The correlation coefficient for this relationship is +0·980, significant at $P = 0{\cdot}001$. There is no suggestion that, at 1,020 trees per acre, the optimum density for maximum yields has been reached.

In contrast, the linear relationship between the tree density and the yield of Amelonado-type cacao, holds good only at lower tree densities, as there was a definite falling off in yields at the greatest density. The results suggest that the optimum density for Amelonado cacao has been reached at about 800 trees per acre.

The vigour of plants and the yield records suggest that closer spacing suits Trinitario better than Amelonado.

In general, differences in yield between treatments are large and of considerable economic importance, especially if the closest four spacings are compared with the widest three. In addition there are also further economic considerations involved, such as capsid infestation, soil nutrient status, and weed growth, all of which are affected by the tree density.

The results suggest that a stand density below 580 trees per acre for both Trinitario and Amelonado cacao in Nigeria is disadvantageous in relation to health and management, and uneconomic in relation to yield.

The results reflect unfavourably on the state of the average Nigerian cacao farm where the average tree density (Kowal, unpublished data) is found to be about 610 per acre. This figure approaches dangerously near the minimum density which appears to be required for a healthy crop and economic yields. In this connexion Russell [1] found a stand

density of between 800–1,100 per acre most advantageous. He considers that a closed canopy is the most important factor in the life of a Nigerian cacao farm.

Effect of Spacing on the Average Number of Pods per Tree and Weight of Beans per Tree

The productivity per tree, of both cacao types, was very low indeed. It was noted by the writer in 1956 that a high proportion of the trees had not contributed to yields at all while a few individual trees had produced a heavy crop. There is no clear relationship between spacing and the average number of pods per tree. The correlation coefficient for this relationship, measured by the averages obtained for the period 1947/8–1955/6 ($n = 63$) is negative but statistically insignificant. However, if only the last two seasons are considered (1954/5–1955/6), i.e. the seasons after capsid control measures had become effective (see Table 3), there is a quite clear and fairly consistent relationship in which the pod number and the average weight of wet beans per tree tend to be larger at low densities. No significant difference in behaviour between Amelonado and Trinitario types is shown in this respect.

TABLE 3. *Effect of Tree Density on the Number of Pods per Tree, and Weight of Wet Beans per Tree and per Pod (during the period 1954/5–1955/6, after capsid control measures became effective). (Combined yields of Trinitario and Amelonado)*

Tree density per acre	*Average number of pods per tree*	*Average weight of wet beans*	
		per tree, lb.	*per pod, lb.*
1,020	2·7	0·51	0·192
795	3·2	0·81	0·212
683	2·9	0·59	0·224
577	4·7	0·85	0·185
268	4·6	0·81	0·180
221	6·9	1·20	0·170
154	5·7	1·08	0·187
Correlation coeff. ($n = 14$)	−0·766	−0·730	+0·557

The results are similar to those reported for young and mature cacao by Benstead and Wickens [4] in Ghana.

The decrease in yield per tree with increasing tree density was not great enough to lower the yields per acre; in fact, the highest yields per acre were obtained from trees at or approaching the greatest density.

Effect of Spacing on the Average Weight of Wet Beans per Pod

The correlation coefficient between tree densities and average weight of wet beans per pod, for a combined selection of Trinitario and Amelonado, during the 1954/5–1955/6 period, is positive but statistically insignificant.

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STUDIES ON THE NUTRIENT STATUS, AND AFFINITY, OF SOME COCONUT SOILS IN CEYLON

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WITH PLATE I

Summary

This paper reviews the data from twenty-four pot experiments which were part of a study on the nutrient status of some coconut soils in Ceylon. One grass and two legumes were used as test plants.

Five soils, designated 'Subsoil', Lateritic Gravel, Lateritic Loam, Lateritic Sand, and Cinnamon Sand, were all acutely deficient in nitrogen, and in that order they showed increasing deficiency of calcium.

In all five soils, during cropping, available nitrogen fell rapidly to a low and constant level, and there was a common pattern of responses to phosphorus and potassium.

In first harvests there was a big response to phosphorus, but in all subsequent harvests this response was less.

In the early stages of growth there was no response to potassium but thereafter there was increasing deficiency and most plants not receiving potassium died at an age of 120–150 days. Aeration and drying of one soil (Lateritic Gravel) promoted vigorous and healthy growth without addition of potassium.

The Lateritic Sand and Cinnamon Sand were deficient in sulphur and there was evidence of an incipient deficiency of copper. Only the Cinnamon Sand showed a deficiency of boron. No other trace-element deficiencies were recorded.

The data suggest that these soils were all derived from the same, or similar, parent material; and that the Lateritic Loam is the most fertile soil in this series. This hypothesis is discussed in relation to current agricultural practice.

THIS paper reviews the data from twenty-four pot experiments which were part of a study on the nutrient status of some coconut soils in Ceylon. Much of the data from those experiments has already been recorded in publications of the Ceylon Coconut Research Institute [1, 2, 3], wherein the results were discussed with a view to more effective use of fertilizers on coconuts, and to the correction of nutrient deficiencies that might be a limiting factor in the growth and selection of desirable pasture plants. This paper is confined to a discussion on the general pattern of responses. Except for minor variations, that pattern was consistent over five soils, and the data suggest that all were derived from the same, or similar, parent material. This hypothesis would have some bearing on current agricultural practice.

The Coconut Research Institute is situated near the central western coast of Ceylon, about 8 miles north of Negombo. Here there is gently undulating country with ridges of laterite rising to a height of approximately 100 feet. The average annual rainfall is about 78 inches (mean for 22 years), and there are two wet periods, April–June and September–November, corresponding with the south-west and north-east monsoons. February is normally the driest month of the year. Mean monthly maximum temperatures range from 95° F. in February to 87° F. in

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June–August. Mean minimum temperatures range from 73° to 67° F. at the same times.

There are five obviously important soils in the district (Fig. 1). They are briefly described below.

General Description of Five Soils

Lateritic Gravel

This soil is typical of low ridges in the south-western sector of Ceylon. It is essentially a red gravel, overlying and derived from a type of rock (Cabook), which is often quarried, cut into 'bricks', and used for building houses.

The 'soil', as such, seldom exceeds 3 feet in depth and there is no obvious stratification, but a gradual breakdown into separate components (gravel, sand, silt, and clay) as an intimate mixture in the surface layer. Under the prevailing climatic conditions, and with cultivation, breakdown is comparatively rapid, and this may be one reason why natural vegetation, and coconuts, have grown so well on this apparently infertile soil.

Under natural conditions, e.g. in native forests, there is normally a layer of sandy loam, 8 to 9 inches deep, above this soil, but with clearing and the cultivation of commercial crops, there has been considerable erosion and complete removal of the original surface soil. Moreover, the exposed subsoil tends to break down and form a new surface soil which is itself erodable. Transportation is therefore a continuing process.

'Subsoil'

This soil was sampled between depths of 24 and 36 inches (i.e. within 6 inches of the underlying rock) under a typical Lateritic Gravel. It was sieved to remove pebbles above ¼ inch in diameter, and thoroughly mixed to provide uniform material suitable for use in pots. It had no apparent structure, being essentially decomposed Cabook.

Lateritic Loam

Below the ridges and with improved moisture status, the parent material is decomposed to form a somewhat softer, yellow gravel with red mottling, and the subsoil is a typical white kaolin clay, of varying and often considerable depth, down to 50 feet. There is frequently a superimposed layer of grey, loamy sand which may be 1 to 4 feet deep, and which has evidently been transported from adjacent ridges. It is, in effect, a deposition of surface soil from the lateritic ridges, and it is highly erodable.

Lateritic Sand

On the valley floors, or in flat open country, and under the influence of freely moving water, silt and clay fractions have been largely transported and the soil is essentially a grey-white sand overlying kaolinitic clay at a depth of approximately 6 feet. The original laterite has almost completely disappeared and may be represented only by brown and

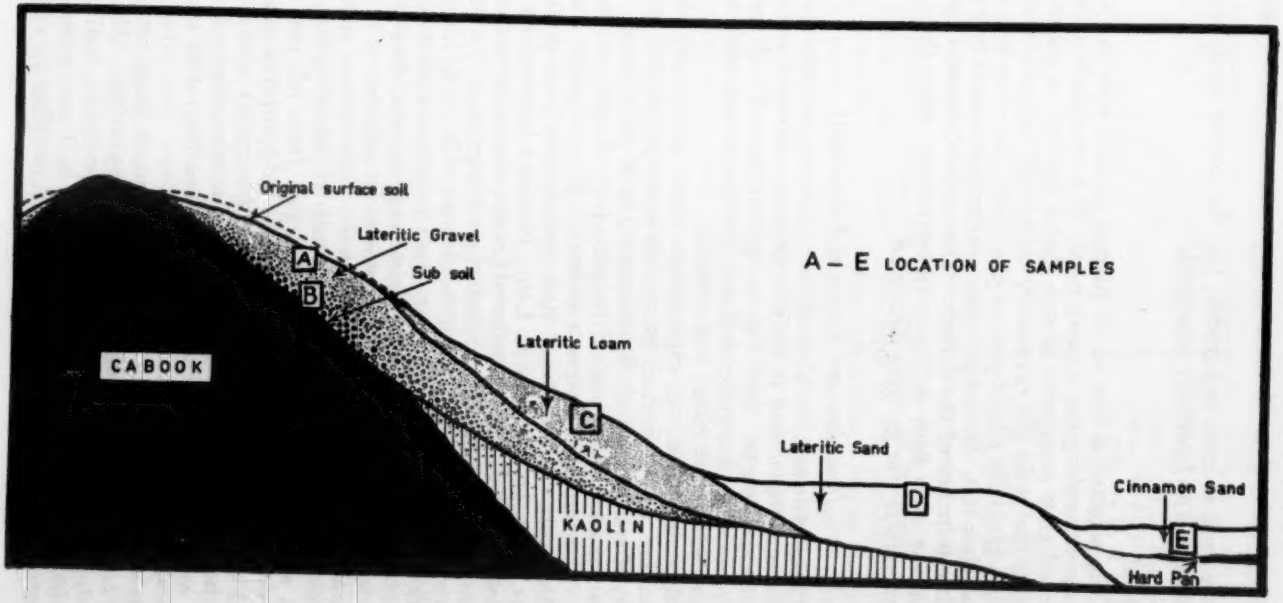

FIG. 1. Diagrammatic representation of the status and location of five Lateritic Soils.

yellow mottling in the clay. There is no apparent stratification and no hard-pan.

The surface sand is loose and friable, but the deeper sands are frequently compressed and partially cemented.

Cinnamon Sand

This soil was selected as one of the poorest coconut soils in Ceylon, typical of large areas along the western coast. It is essentially a leached sand, developed after emergence of sub-coastal lagoons, or possibly in low-lying areas that were not necessarily completely submerged at any time. There is generally a hard-pan, or clay layer, occurring at a depth of approximately 5 feet. Drainage is poor, and in wet seasons free water rises to within 6 inches of the surface. The name Cinnamon Sand is derived from the early days of European agriculture, when these soils were used extensively for growing cinnamon.

Procedure and Design of Experiments

On each type of soil, samples were taken from twenty to thirty different places and were compounded to provide uniform material for use in a series of pot experiments. With one exception ('subsoil'), all samples were taken to a depth of 9 inches and only the coarser vegetable matter (leaves, stems, and larger roots) was excluded.

Unless otherwise stated, all experiments were of factorial design, single replication, and individual treatments were applied to 2,000 gm. (dry weight) of soil in a 6-inch flower-pot made of polystyrene. Their effects were measured in terms of the yield (dry weight) of plants in every pot. The test plants were a perennial pasture grass, and two legumes: they were used to obtain basic information from short-term experiments. *Paspalum commersonii* Lam., *Phaseolus lathyroides* L., and lucerne (*Medicago sativa* L.) were selected because the author was familiar with deficiency symptoms in those plants [4]. All are good 'pot plants': the grass is a good indicator plant for deficiencies of N, P, K, Ca, S, Cu, Zn, Mn, and Fe; the two legumes were used as indicator plants for any deficiency of Mg, B, and Mo. In all legume experiments, the soils were inoculated with imported Australian strains of Rhizobium.

The nutrients were all AR-grade chemicals. Calcium was applied as $CaCO_3$ mixed with the upper 1½ inches of soil; all others were supplied from stock solutions allowing ready conversion from ml./pot, to the equivalent dressings in lb. or cwt./acre (Table 1). Appropriate quantities were added to a set of beakers representing all treatments in any experiment, and then diluted to 250 ml., before being transferred to pots of soil. All plants were grown from seed and surplus seedlings were removed, leaving one plant of the same size in each pot.

The pots were watered daily, their water content being brought to a constant level (85 per cent. of field capacity) by weight. The water was filtered, passed through a commercial water softener, distilled and redistilled before use. The final distillation was in 'Pyrex' glass.

The plants were grown in a special Phytosolarium (Plate 1), a building

TABLE 1. *Stock Solutions for all Nutrients used in Experiments 1–24*

Nutrient	*Formulation*	*Equivalent rate of application per acre, using 2 ml. stock solution per pot*
N	$(NH_4)_2SO_4$	5 cwt.: 118 lb. N+135 lb. S
P	$NaH_2PO_4.2H_2O$	3 cwt.: 67 lb. P+44 lb. Na
K	K_2SO_4	1·5 cwt.: 75 lb. K+34 lb. S
Mg	$MgSO_4.7H_2O$	0·5 cwt.: 6 lb. Mg+7 lb. S
Cu	$CuSO_4.5H_2O$	7 lb.: 1·8 lb. Cu+0·9 lb. S
Zn	$ZnSO_4.7H_2O$	7 lb.: 1·5 lb. Zn+0·8 lb. S
Mn	$MnSO_4.4H_2O$	14 lb.: 3·5 lb. Mn+2·0 lb. S
Fe	$FeSO_4.7H_2O$	14 lb.: 2·8 lb. Fe+1·6 lb. S
B	$Na_2B_4O_7.10H_2O$	4·4 lb.: 0·5 lb. B+0·5 lb. Na
Mo	$(NH_4)_6Mo_7O_{24}.4H_2O$	1·4 lb.: 0·5 lb. Mo+0·7 lb. N

with aluminium framework covered with an envelope of 'Cascalite' (resin-bonded fibre glass). The sides of the building, above bench height, were hinged to allow free ventilation. Inside the building the mean monthly maximum temperature was 107±0·56° F., for a period of 12 months, ranging from 111° F. in March 1957 to 104° F. in August 1956: the mean monthly minimum temperature was 77±0·89° F., ranging from 80° F. in May 1956 to 71° F. in January 1957. Light was diffuse and apparently uniform and the plants showed no symptoms of inadequate illumination. The pots were held on movable tables, twenty-four per table, and their position and orientation were systematically changed daily to ensure even lighting.

All experiments were harvested when the more advanced plants reached an early-flowering stage. Yields included all tissues above a height of 1½ inches. The plants were then allowed to make new growth and with very few exceptions the experiments were harvested three or four times.

The data from successive harvests showed the direct effect from all treatments, by comparison with the yield from untreated pots (i.e. unhealthy plants that were deficient in one or more nutrients), and in some cases increments of 3,000 per cent. were recorded (Fig. 2). As a more useful comparison and in order to assess the importance of naturally occurring deficiencies, the data were reanalysed and the effect of *absence* of individual nutrients was measured in terms of a 'Relative Yield', using the yield from the complete fertilizer treatment as control,

$$\text{i.e. Relative Yield} = \frac{Y}{A} \times 100,$$

where A = yield with all nutrients in adequate supply, and Y = yield in absence of a single, specified nutrient.

A relative yield would not be valid if there were any shortage in the supply, or availability, of nutrients in the control (A). Therefore in any experiment, if there were specific deficiency symptoms in the control, if there was a big response to any nutrient, or if there was any other reason to suspect that the original dosage might be sub-optimal, then more of the original stock solution was added to appropriate pots

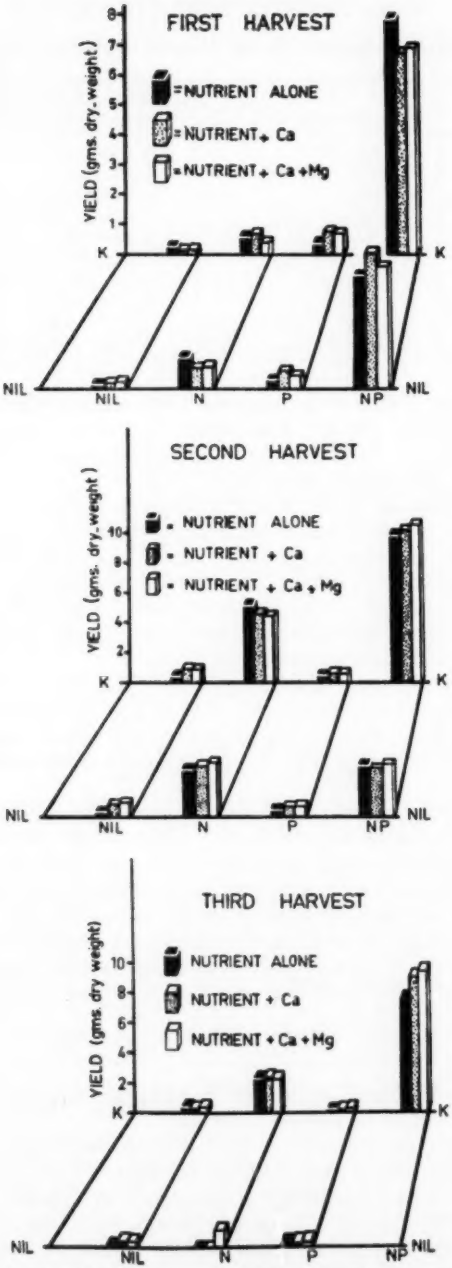

FIG. 2. *Experiment 1* showing mean yields for all effective treatments in successive harvests of *Paspalum commersonii*.

throughout the experiment. This procedure carried with it some risk of over-dosage, but in that event—i.e. if there were adverse effects from over-dosage of any nutrient—then Relative Yields would exceed 100 per cent., and appropriate adjustments could be made (see under Results, p. 43).

A harmful excess of any one nutrient, with consequent reduction in yields for the complete fertilizer treatment (*A*), would also affect the Relative Yield values for all other nutrients and in a few instances (especially phosphorus on lateritic loam) there was a depression in yield due to application of a nutrient at moderate level. In such cases Relative Yields for all other nutrients were computed by the same formula: using *B* (i.e. yield for the complete fertilizer minus the nutrient causing depression) in place of *A* (complete fertilizer).

Record of Experiments

Of the twenty-four experiments comprising this study, the following sixteen are referred to in the text. All nutrients were applied in forms and doses enumerated in Table 1, and where a further amount of any nutrient was applied in the course of an experiment the total dosage (in cwt. or lb./acre) is shown in parentheses after the appropriate symbol.

'*Subsoil*'

Experiment 1. A 2^5 factorial experiment using one species (*Paspalum commersonii*) and five nutrients, N(15), P(6), K(6), Ca, and Mg(4). All pots were given a basal dressing of Cu, Zn, Mn, Fe, B(8·4), and Mo. Harvested three times, at ages of 38, 89, and 129 days.

Lateritic Gravel

Experiment 2. A 2^7 factorial experiment using two species (*Paspalum commersonii* and *Phaseolus lathyroides*) and six nutrients, N(10), P(6), K, Cu(14), Mo, and 'X' ('X' being a mixture of Mg, Mn, Zn, and Fe). All pots were given a basal dressing of boron. The Paspalum was harvested three times, at ages of 44, 81, and 132 days; the Phaseolus twice, at 60 and 90 days.

Experiment 3. A 2^7 factorial experiment using two species (*Paspalum commersonii* and *Phaseolus lathyroides*) and six nutrients, K, Ca, Mg, Fe, Mo, and 'A' ('A' being a mixture of Cu, Zn, and Mn). All pots were given a basal dressing of N(10), P(6), and B(8·4). The Paspalum was harvested four times, at ages of 37, 71, 105, and 149 days; the Phaseolus three times, at ages of 47, 81, and 105 days.

Experiment 4. A 2^6 factorial experiment using two species (*Paspalum commersonii* and *Phaseolus lathyroides*) and five nutrients, N(15), P, Cu, Zn, and Mn. All pots were given a basal dressing of P(6), Ca, Mg, Fe, B(7·5), and Mo. Both species were harvested three times, at ages of 49, 84, and 126 days.

Lateritic Loam

Experiment 9. A 2^6 factorial experiment using one species (*Paspalum commersonii*) and six nutrients, N(15), P, K(6), Ca, Mg(1·5), and 'X'

('X' being a mixture of Cu(14), Zn(14), Mn, B, and Mo). Harvested three times, at ages of 42, 74, and 108 days.

Lateritic Sand

Experiment 12. A 2^6 factorial experiment, using one species (*Paspalum commersonii*) and six nutrients, N(15), P(6), K(3), Ca, Mg, and 'X' ('X' being a mixture of Cu, Zn, Mn, B, and Mo). Harvested four times, i.e. at ages of 48, 104, 136, and 167 days.

Cinnamon Sand

Experiment 15. A 2^7 factorial experiment, using two species (*Paspalum commersonii* and *Phaseolus lathyroides*) and six nutrients, K, Mg(4), Fe, Mo, Cu(14), and Zn. All pots were given a basal dressing of N(10), P(6), Ca, Mn, and B. Harvested twice, at ages of 39 and 69 days.

Experiment 16. A $2^5 \times 4^1$ factorial experiment, using one species (*Paspalum commersonii*) and five nutrients P, K(4·5), Mg, Fe, and Cu. There were four levels of N (0, 1½(3), 3(6), and 6(12) cwt. $(NH_4)_2SO_4$/acre). All pots were given a basal dressing of Ca(10) and B. Harvested three times, at ages of 23, 53, and 90 days.

Experiment 17. A $2^2 \times 4^1$ (R_2) factorial experiment, using one species (*Paspalum commersonii*) and two nutrients (Cu(14) and Fe). There were four levels of N (0, 3(6), 6(12), and 9(18) cwt. NH_4NO_3/acre). All pots were given a basal dressing of P, K(9), and Ca(15). Harvested three times, at ages of 38, 56, and 77 days.

Experiments 18 and 19. In these experiments two major nutrients, P, Ca; or K, Mg, were applied at four levels and all pots were given a basal dressing of N and B and of the two major nutrients not applied in increasing doses. Both experiments were harvested four times, at ages of 20, 47, 78, and 116 days.

Experiments 20, 21, and 22. In these experiments two major nutrients, P, Mg; K, Ca; or P, K, were applied at four levels and all pots were given a basal dressing of N, Cu, and B and of the three major nutrients not applied in increasing dosage. All three experiments were harvested four times, at ages of 31, 46, 100, and 121 days.

Experiment 23. A $3^1 \times 3^1$ (R_2) factorial experiment, using three species (*Paspalum commersonii*, *Phaseolus lathyroides*, and *Medicago sativa*) and three levels of B (0, 3, and 6 lb. $Na_2B_4O_7 \cdot 10H_2O$/acre). All pots were given a basal dressing of N, P(6), K, Ca, Mg(4), Cu(14), Zn, Fe, Mn, and Mo. The Paspalum and Medicago were harvested twice, at ages of 46 and 90 days, and at 64 and 117 days, respectively. The Phaseolus was harvested once, at 46 days.

Experiment 24. A simple comparison of two treatments 'nil' and 'sulphur', using two species (*Paspalum commersonii* and *Phaseolus lathyroides*). There were ten formulations comprising five mixtures containing sulphur and five with no sulphur. All formulations contained the same amounts of N, Mg, and Ca. The basic treatment was S_4 (0·175 gm./pot = 123 lb./acre, of S). All pots were given a basal dressing of K(KCl), and P. Harvested once, the Paspalum at the age of 52 days, the Phaseolus at 84 days.

Results

In all the twenty-four experiments there were major responses to N, P, K, and Ca, but magnesium had no significant effect on yield, and with few exceptions there was no response to sulphur, or to any of the trace elements. In Lateritic Sand and in Cinnamon Sand there was a big response to sulphur, and some evidence of an incipient deficiency of copper. A deficiency of boron was recorded for the Cinnamon Sand.

'*Subsoil*' (Experiment 1)

In the first harvest of Experiment 1 there was a very small response to N and to P, but responses to NP and NPK were very large (see Fig. 2). In the second harvest there was a much greater response to N (comparable with NP); there was no response to P but again a very large response to NPK. In the third harvest only NK and NPK had any appreciable effect on yield. Essentially the data for successive harvests show that there was an increasing response to N and K, and a decreasing response to P.

Lateritic Gravel (Experiment 2)

In Experiment 2 and in the first harvest of *Paspalum commersonii*, N and K had no significant effect, but there was an appreciable response to P and to NP (Fig. 3). In the second harvest there was an appreciable response to N (equivalent to NP); P was responsible for some depression in yield and there was some effect from K. In the third harvest only N (increment of 250 per cent.), NK (increment of 675 per cent.), and NPK (increment exceeding 1,000 per cent.) had any significant effect on yield. Here again in successive harvests there were increasing effects from N and K and a decreasing effect from P in association with N and K.

In the early (pre-harvest) stages of growth, *Phaseolus lathyroides* showed essentially the same responses to N, P, and K, but at a later stage the plants in all 'nil' treatments made relatively vigorous growth, and data for the first harvest showed quite small effects from N and P. There was no significant response to K (Fig. 4).

In the second harvest, there was an appreciable response to P (increment of 91 per cent.), to N (increment of 46 per cent.), and to NP (increment of 74 per cent.). However, those effects would be complicated by the activity of symbiotic bacteria, and might be more correctly recorded as follows:

P = Symbiotic Nitrogen+P	(91 per cent.)
N = Fertilizer Nitrogen	(46 per cent.)
NP = Fertilizer N+P	(74 per cent.)

There was also an appreciable response to K, ranging from an increment of 39 per cent. for K alone (≡ NK), to a mean value of 175 per cent. for KP (≡ NPK), and NPK.

Comparison of 'Subsoil' and Lateritic Gravel

In these two soils the nature and the magnitude of responses to N, P, and K varied from one harvest to the next and the pattern of responses

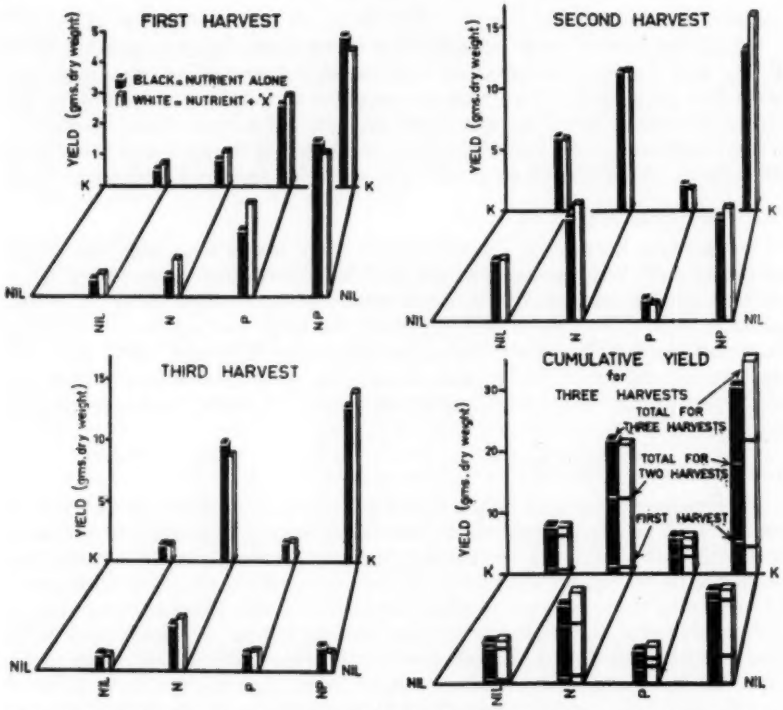

FIG. 3. *Experiment 2* showing mean yields for all effective treatments in successive harvests of *Paspalum commersonii*.

was essentially the same for both soils. Any apparent differences could be interpreted in terms of their original nitrogen status.

For example, in the first harvest of Experiment 1, N alone gave an increment of 200 per cent. and P alone an increment of 135 per cent. In Experiment 2 there was no response to N, and the response to P was much greater (increment of 400 per cent.). However, if the Lateritic Gravel contained more available nitrogen then a smaller response to N would follow automatically, and the larger response to P must be interpreted as a PN interaction. In other words, for Experiment 2, 'P alone' should be read as 'Pn' (where n represents the natural level of available nitrogen in that soil).

In the second harvest of Experiment 2, N alone and NP were equally effective (increments of 100 and 113 per cent.) and there was some depression with P alone (not significant). In the third harvest, and in the total yield from three harvests, there was no effect from P alone. Thus with these two soils any response to phosphorus was completely dependent on available nitrogen, which was either initially low, or readily exhausted.

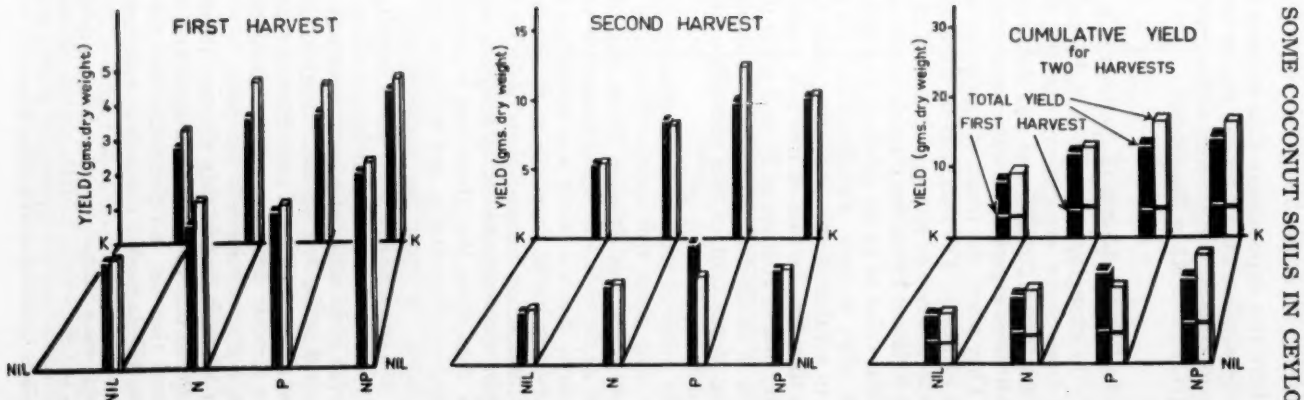

FIG. 4. *Experiment 2* showing mean yields for all effective treatments in successive harvests of *Phaseolus lathyroides*.

The data from these two experiments thus suggest that surface and subsoil are essentially similar, except for the higher levels of naturally occurring available nitrogen in surface soil, and a greater deficiency of all three nutrients (N, P, and K) in the subsoil.

Relative Yields for the Lateritic Gravel (Experiments 2, 3, and 4)

In order to clarify the changing response to N, P, and K in successive harvests, the data from three experiments on the Lateritic Gravel (Experiments 2, 3, and 4) were reanalysed and Relative Yields for successive harvests of all three experiments were then combined in a single diagram (Fig. 5). They show the trend of responses over a period of some 150 days after planting. The data may be summarized as follows:

No nitrogen. In the absence of nitrogen, but with all other nutrients in adequate supply, Relative Yields for *Paspalum commersonii* decreased steadily from an initial value of 47 (at 44 days) to a final and consistent value of 16 per cent. after 80 days. Relative Yields for *Phaseolus lathyroides* rose steadily to a value of 100, indicating effective nodulation of the legume. It can therefore be said of this soil, under the conditions of these experiments, that in absence of N, and when the initial supply of available nitrogen is exhausted, no amount of other nutrients will give yields exceeding 16 per cent. of that obtainable when all nutrients are present in adequate supply.

No phosphorus. In order to portray the continuing effect of absence of phosphorus, the data from two species (Phaseolus and Paspalum) were combined; they show that Relative Yields rose steadily from an initial value of 20 (at 44 days) to a final and consistent value of approximately 70 after 80 days. Such a result was somewhat unexpected and in this case the very big initial response to P cannot be interpreted in terms of any PN interaction because these Relative Yields were derived exclusively from treatments receiving adequate supplies of N. On the other hand, the data show that there was a definite and progressive improvement in phosphate status, and while no full or satisfactory explanation is available,[1] it must be assumed that available soil-phosphorus, which was originally in fairly short supply, had increased, possibly as a result of some chemical or biological changes in the soil.

No potassium. In the early stages of growth there was very little effect from absence of K, and in the first 60 days Relative Yields from all K_0 treatments fluctuated about a value of 100. However, in all subsequent harvests there was a steadily declining yield, culminating in the death of K_0 plants at an age of approximately 150 days.

It is of particular interest that in this diagram there was a marked difference in the shape of curves for 'no nitrogen' and 'no phosphorus' on the one hand, and that for 'no potassium' on the other. In the former cases Relative Yields tended towards an asymptote representing

[1] Since this manuscript was submitted the author has seen data from experiments by Williams, Bromfield, and Williams (C.S.I.R.O., private communication) showing that under anaerobic conditions there is an appreciable increase in available P in soils where phosphorus is held in combination with ferric salts.

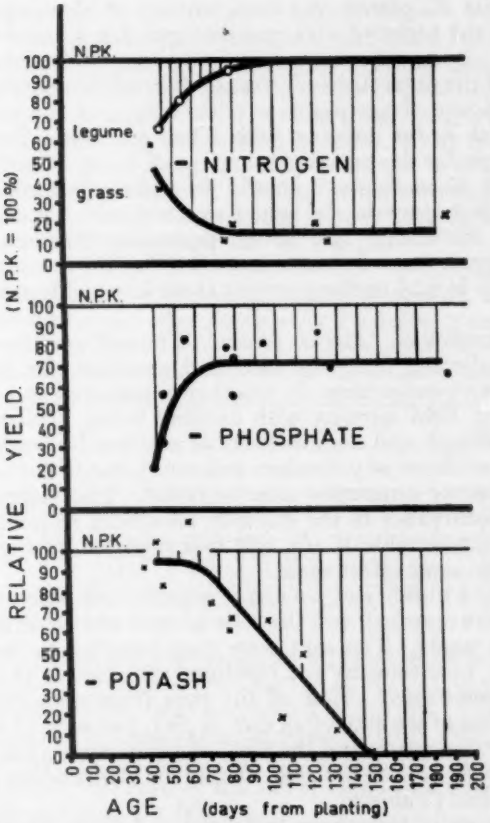

FIG. 5. Diagram compounded from three experiments (Nos. 2, 3, and 4) showing progressive effects from absence of N, P, and K.

the final level of production where growth is dependent on the availability of a particular soil-nutrient, but in the latter case Relative Yields decreased steadily to zero, and there appeared to be no readily liberated reserve of soil-potassium.

Loss of available potassium in Lateritic Gravel. This pattern of response has been recorded in a number of these lateritic soils and in later experiments both soil and plants have been analysed in order to gain further information on this point.

Bulk samples from a third harvest of *Paspalum commersonii* (including all tissues above a height of 1 inch) were analysed. Those from K_+ and K_0 plants contained 2·71 and 0·87 per cent. K_2O, respectively. In Experiment 3, cumulative yields from twenty-four pots were 115 gm. (K_+) and 75 gm. (K_0), and assuming a steady decline in the potassium

content of the K_0 plants, the total amount of elemental K extracted would be in the order of 0·11 and 0·06 gm. for K_+ and K_0 treatments respectively.

Analysis of the untreated soil—using Milne's hydrochloric acid method [5]—gave a figure of 240 p.p.m. available K_2O, or approximately 0·355 gm. elemental K for any pot with 2,000 gm. soil. Even allowing a suitable margin for the potassium content of roots, those figures suggest that available K in this soil should be sufficient to meet all requirements for plant growth. In fact, there was both visual and chemical evidence of increasing, and acute, potassium deficiency. The data therefore suggest some decrease in availability (or fixation) of available K as the only logical explanation for these low yields and the death of K_0 plants.

Effect of aeration on Lateritic Gravel. The soil used for these experiments was collected from the field and air-dried, for convenience of storage in large wooden bins. It was then transferred to pots, and raised to 85 per cent. field capacity with distilled water. There was no provision for drainage, and no possibility of any loss by leaching. Initially there was no evidence of potassium deficiency, but in the course of some 18–20 weeks acute symptoms were recorded. This suggested that air-drying and disturbance of the soil may have been responsible for some increase in exchangeable K [6], and that repeated drying and aeration might have the same effect again.

Accordingly a number of pots from experiments with and without K treatments were emptied, and the soils aerated and air-dried for periods of 1 and of 2 weeks. The soils were then returned to the pots, raised to 85 per cent. field capacity and replanted with seed of the same species (*Paspalum commersonii*). Half of the pots from each treatment were given a dressing of the rate of 4½ cwt. K_2SO_4 per acre. The new plants all grew quite vigorously and the yield of plants which had not received additional K was 40–100 per cent. of that for plants where additional K had been applied (Table 2).

These data show that there had been a definite improvement, i.e. some alleviation of potassium deficiency, in soils that were aerated and dried.

Relative Yields for the Lateritic Loam (Experiment 9)

The pattern of Relative Yields for the Lateritic Gravel (Fig. 5) was derived from three essentially similar experiments and, in the absence of comparable data, Relative Yields for the Lateritic Loam were derived from Experiment 9. In that experiment neither Mg nor 'X' (combined trace elements) had any significant effect on yield, and there were no significant interactions involving those two treatments. The data from four treatments (nil, Mg, X, and MgX) were therefore treated as replicates, and Relative Yields for each replicate were separately computed. Finally, and in order to obtain some measure of reliability, Mean Relative Yields, and standard deviations, were calculated from those individual values, and the data for successive harvests were plotted as a ribbon curve (Fig. 6).

The two diagrams (Figs. 5 and 6) are basically similar, but in Experiment 9 there was an anomaly in the second and third harvests, where the mean Relative Yield for 'no phosphorus' was significantly greater than 100. A Relative Yield of more than 100 is possible only if the particular nutrient is having an adverse effect on plant growth: e.g. any toxic substance would have this effect. Too much of any nutrient could also have this effect, but only if all other nutrients were present, and available, in sufficient quantity. Under any other conditions, e.g. with incipient deficiency of a second nutrient, a new limiting factor would intrude, and Relative Yields could not exceed 100.

TABLE 2. *Comparative Yields from Plants of* Paspalum commersonii *grown on Lateritic Gravel after Aeration for Periods of 1 and 2 Weeks*

Experiment No.	1				2				3			
Soil aerated for . .	1 week				2 weeks				2 weeks			
Original K treatment (cwt./acre, K_2SO_4)	4½		0		4½		0		4½		0	
Comparative yield (Third harvest)	100		0		100		0		100		0	
Subsequent K treatment (cwt./acre, K_2SO_4)	4½	0	4½	0	4½	0	4½	0	4½	0	4½	0
Comparative yield	100	43 ±8·2	100	34 ±2·3	100	122 ±8·3	100	89 ±6·0	100	74 ±3·4	100	61 ±7·7

Mean value for comparative yield on aerated soil $K_{4\frac{1}{2}}:K_0 = 100:70$

The data from this experiment thus showed that there was no deficiency of any nutrient in the complete fertilizer (N, P, K, Ca), but a depression in yield where phosphorus had been added to the soil. For that reason, and because there were consequent interactions (NP, PCa, and NPCa), Relative Yields for 'no nitrogen', 'no potassium', and 'no calcium'—in the second and third harvests of this experiment—were recalculated on the basis of 100 per cent. for NKCa.

In effect these data showed that the general pattern of responses in Lateritic Loam was essentially similar to that recorded from Experiments 2, 3, and 4 (Lateritic Gravel). However, in this soil the natural level of available phosphorus appeared to be somewhat higher, and there was an apparent depression in yield from the addition of 3 cwt./acre of sodium phosphate.

Relative Yields for the Lateritic Sand (Experiment 12)

Essentially similar data for the Lateritic Sand were available from Experiment 12, and as in Experiment 9, neither Mg nor 'X' had any significant effect on yield. The same four treatments (nil, Mg, X, and MgX) were treated as replicates, and Mean Relative Yields for the first three harvests were calculated on the basis of 100 for NPKCa. In a fourth harvest Relative Yields and mean values for N, K, and Ca were calculated on the basis of 100 for NKCa (Fig. 7).

In the absence of P, Relative Yields rose sharply from an initial value

of $11 \pm 1{\cdot}2$ in the first harvest to an overall mean value of $64 \pm 5{\cdot}8$ in the second and third harvests. There was no depression in yield from 3 cwt./acre NaH_2PO_4, but in a fourth harvest, and with a total application of 6 cwt./acre, yields were depressed by as much as 30 per cent.

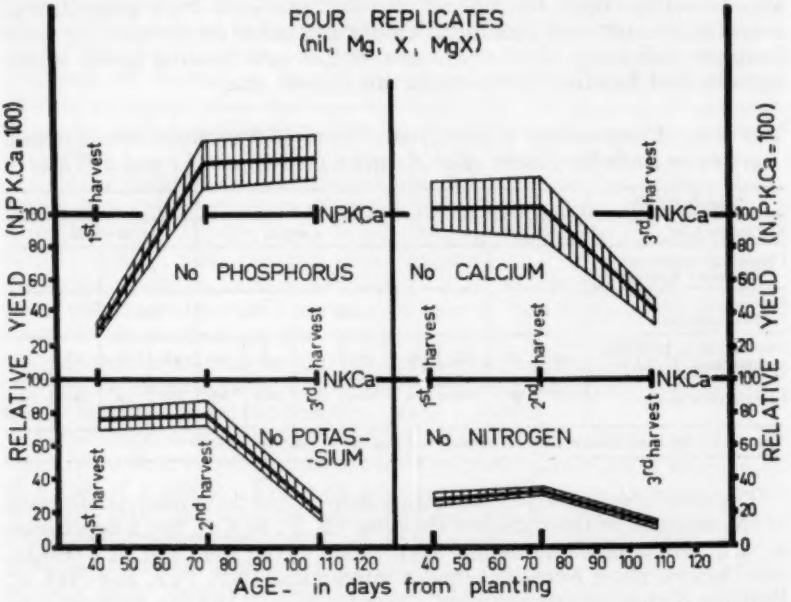

FIG. 6. *Experiment 9* showing mean and standard deviation of Relative Yields in the absence of single nutrients, and in successive harvests.

In the absence of K, and in the first three harvests, Relative Yields decreased steadily from an initial value of $95 \pm 9{\cdot}8$ (first harvest), through $24 \pm 1{\cdot}0$ (second harvest), to $9 \pm 1{\cdot}3$ (third harvest). The decline, however, was somewhat less steep than in other soils, and there was a reversed inflexion suggesting some loss of any capacity for K-fixation in this soil. In the fourth harvest all K_0 plants were dead.

In the absence of Ca, Relative Yields declined rapidly from an initial value of $105 \pm 14{\cdot}5$ for the first harvest, to $18 \pm 3{\cdot}0$ and $6 \pm 3{\cdot}6$ for the second and third harvests, respectively. In the fourth harvest two of the four Ca_0 plants were dead and the Mean Relative Yield (NKCa = 100) was 14 ± 2.

In the absence of N, and in the first three harvests, Relative Yields were consistently low (overall mean value of $10 \pm 1{\cdot}2$). Prior to the first harvest there was visual evidence of somewhat better growth, but that effect was short-lived.

Relative Yields for the Cinnamon Sand (Experiments 15–24)

Data for the Cinnamon Sand were gleaned from a number of experiments in which the several nutrients had been applied in increasing dosage. The general pattern of responses is portrayed in Fig. 7.

As in previous experiments, the data for successive harvests show that there was an obvious trend towards some increase in the level of available P, but there was no evidence of any depression from 3 cwt./acre NaH_2PO_4. There was a steady decline in the levels of available K and Ca.

In the absence of K, Relative Yields for the three harvests steadily declined, and in subsequent harvests they tended towards an asymptote at a value of approximately 15. In the absence of Ca, Relative Yields were initially smaller than in other soils and they decreased steadily to zero after approximately 120 days. There was no evidence of any supply of readily liberated reserves of soil-calcium.

Discussion

In all these five soils there was a similar pattern of responses (Fig. 8), which suggests that they are derived from the one, or similar, parent material, and that, in turn, from the underlying rock (Cabook).

From general observation it would appear that when Cabook is exposed to atmospheric conditions there is fairly rapid oxidation, a hardening of the surface, and formation of a typical Lateritic outcrop. Where it is not exposed (i.e. under semi-anaerobic conditions, and in presence of soil moisture) there is progressive decomposition which may vary in accordance with prevailing moisture status.

On the ridges (i.e. with limited soil moisture and appreciable aeration), 'Subsoil', Lateritic Gravel, and eventually Lateritic Loam are formed, but at lower levels (i.e. with more soil moisture and less aeration) decomposition is more rapid, with formation of a softer, yellowish gravel, and eventually kaolinitic clay.

On the Lateritic Gravel the surface soil is highly erodable and, at least under cultivation, it is readily transported to lower levels where it accumulates as a colluvial deposit of Lateritic Loam, or as degraded products thereof, namely Lateritic Sand or Cinnamon Sand. On the latter, leaching is a factor of obvious importance and there is a definite hardpan, but it would appear that erosion has been the major causative agent in development of this catena.

The nutrient status of these five soils may be summarized as follows:

'*Subsoil*'. In the 'Subsoil' there is no deficiency of available calcium, but there is an acute deficiency of nitrogen, of phosphorus, and of potassium. The levels of available K and P are comparatively low, and affected by chemical, or by biological activity, as described under Results, p. 43. Nitrogen—which is not a mineral nutrient—is acutely deficient in all five soils.

Lateritic Gravel. In Lateritic Gravel the supply of available nutrients is somewhat greater and in the first harvest only nitrogen and phos-

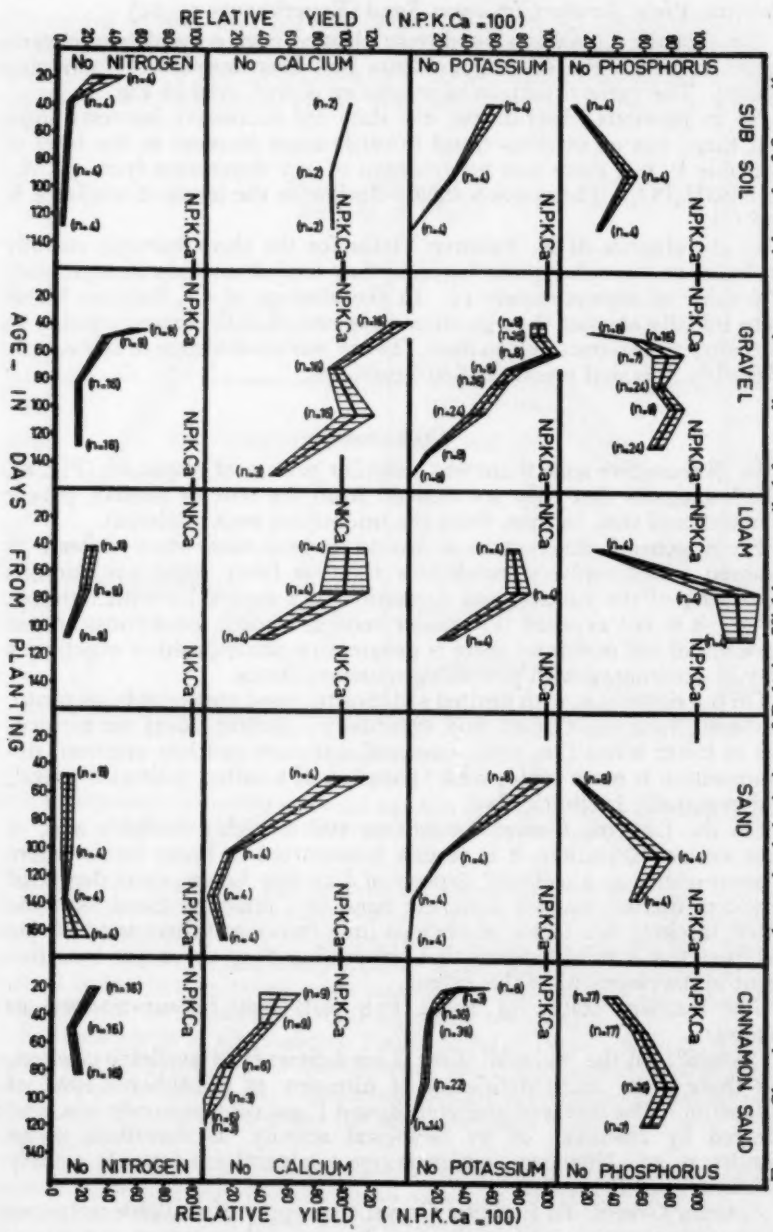

FIG. 7. Showing mean and standard deviation of Relative Yields, compiled from all experiments with each of five soils.

phorus were in short supply. Addition of calcium led to some initial depression in yield (excess Ca).

In later harvests there was increasingly acute deficiency of K; in absence of P, Relative Yields rose to a steady value of 70. There was also some deficiency of Ca, which would follow naturally from leaching of the surface soil.[1]

Lateritic Loam. In the Lateritic Loam a deficiency of Ca appeared somewhat earlier (after approximately 80 days). In the absence of K, Relative Yields were initially high and held to the order of 75 per cent. for nearly 80 days. Naturally available P rose steadily, and there was some depression in yield from 3 cwt./acre $NaH_2PO_4.2H_2O$.

The Lateritic Loam would appear to be the most fertile soil derived from the original parent material. Moreover, this is the only soil with an appreciable clay fraction, and it has a much better structure.

Lateritic Sand and *Cinnamon Sand.* In Lateritic Sand and in Cinnamon Sand (essentially similar soils to a depth of 9 inches), there is an obvious lack of fertility which can be attributed to leaching or to the solution of nutrients in flowing water. Both soils showed an early and acute deficiency of Ca, and the supply of available K was relatively small, and short-lived. There was also some change in the slope and inflexion of the 'no-potassium' curves, which suggests a progressive loss of any capacity for K-fixation. In the absence of P, Relative Yields followed the original pattern (cf. 'Subsoil', Gravel, and Loam), but the eventual supply of available P was appreciably reduced and maximum Relative Yields did not exceed a value of 60. Also in these two soils a deficiency of sulphur (acute in Cinnamon Sand) was recorded and there was some evidence of an incipient deficiency of copper. Boron deficiency has been recorded in the 'Cinnamon Sand' [2, 3].

Note on Current Agricultural Practice

In current agricultural practice any relationship between these five soils has received very little attention, but it is a matter of some practical importance that they are related, and that the Lateritic Loam is the most fertile soil of this series. From a national point of view it is important to realize that movement of this soil to the valley floors implies severe washing or leaching, and thereby a loss of very great natural resources. Adequate control of erosion would therefore be essential to any form of good management.

On the Lateritic Gravel this would involve construction and maintenance of contour banks, and on current evidence it is likely that some form of soil aeration (deep cultivation, or use of a subsoiling tine) would improve the natural level of available K. Correct fertilizer practice would vary with the amount and frequency of aeration and the amount of Lateritic Loam retained [1, 3].

On the Lateritic Loam erosion control would be even more important, and it is likely that soil aeration would be similarly advantageous.

[1] In ancillary experiments 87·3 lb./acre Ca was removed from 6,400 gm. soil in 26 litres of leachate (distilled water).

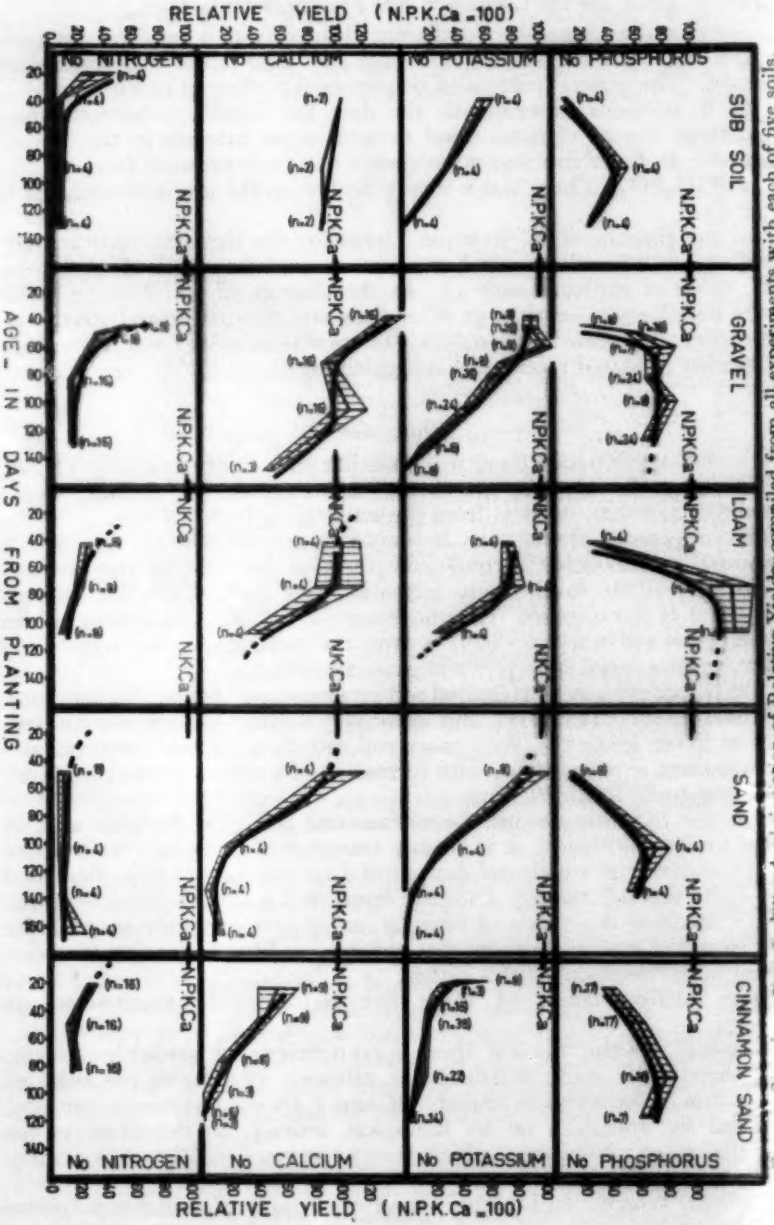

FIG. 3.—Curves showing relationship between relative yield and age of plants grown in pots of soil with each of five soils.

phorus were in short supply. Addition of calcium led to some initial depression in yield (excess Ca).

In later harvests there was increasingly acute deficiency of K; in absence of P, Relative Yields rose to a steady value of 70. There was also some deficiency of Ca, which would follow naturally from leaching of the surface soil.[1]

Lateritic Loam. In the Lateritic Loam a deficiency of Ca appeared somewhat earlier (after approximately 80 days). In the absence of K, Relative Yields were initially high and held to the order of 75 per cent. for nearly 80 days. Naturally available P rose steadily, and there was some depression in yield from 3 cwt./acre $NaH_2PO_4.2H_2O$.

The Lateritic Loam would appear to be the most fertile soil derived from the original parent material. Moreover, this is the only soil with an appreciable clay fraction, and it has a much better structure.

Lateritic Sand and *Cinnamon Sand.* In Lateritic Sand and in Cinnamon Sand (essentially similar soils to a depth of 9 inches), there is an obvious lack of fertility which can be attributed to leaching or to the solution of nutrients in flowing water. Both soils showed an early and acute deficiency of Ca, and the supply of available K was relatively small, and short-lived. There was also some change in the slope and inflexion of the 'no-potassium' curves, which suggests a progressive loss of any capacity for K-fixation. In the absence of P, Relative Yields followed the original pattern (cf. 'Subsoil', Gravel, and Loam) but the eventual supply of available P was appreciably reduced and maximum Relative Yields did not exceed a value of 80. Also in these two soils a deficiency of sulphur (acute in Cinnamon Sand) was recorded and there was some evidence of an incipient deficiency of copper. Boron deficiency has been recorded in the 'Cinnamon Sand' [2, 3].

Note on Current Agricultural Practice

In current agricultural practice, any relationship between these five soils has received very little attention, but it is a matter of some practical importance that they are related, and that the Lateritic Loam is the most fertile soil of this series. From a national point of view it is important to realize that movement of this soil to the valley floors implies severe washing or leaching, and thereby a loss of very great natural resources. Adequate control of erosion would therefore be essential to any form of good management.

On the Lateritic Gravel this would involve construction and maintenance of contour banks, and on current evidence it is likely that some form of soil aeration (deep cultivation, or use of a subsoiling tine) would improve the natural level of available K. Correct fertilizer practice would vary with the amount and frequency of aeration and the amount of Lateritic Loam retained [1, 3].

On the Lateritic Loam erosion control would be even more important, and it is likely that soil aeration would be similarly advantageous.

[1] In ancillary experiments 87·3 lb./acre Ca was removed from 6,400 gm. soil in 26 litres of leachate (distilled water).

Fertilizer practice should be carefully controlled, and, in particular, indiscriminate applications of phosphorus should be avoided [3].

On the Lateritic Sand any form of cultivation or disturbance of the surface soil should be avoided, and a major objective should be to establish a complete ground cover of leguminous plants, or pasture. Heavy dressings of the major nutrients (N, K, Ca) and of sulphur and a small amount of copper sulphate may be required. A light dressing of phosphorus (not exceeding 3 cwt./acre $NaH_2PO_42H_2O$) might be advantageous for the establishment of desirable species [3].

On the Cinnamon Sand there is a need for drainage, to remove excess water during wet seasons, and very heavy dressings of N, K, and Ca would be required for satisfactory plant growth. Smaller amounts (about 1 cwt./acre) of P and S, and 6–8 lb./acre of $CuSO_4$ and of borax may also be required [2]. Wide ridging, to facilitate drainage and to provide a greater depth of soil above the water table, might have some advantages.

On all these soils, use of a standard fertilizer mixture seems undesirable. Individual nutrients should be applied in accordance with prevailing conditions and the changing requirements for plant growth.

Acknowledgements. The author wishes to record sincere appreciation of assistance and advice from all members of the Coconut Research Institute staff, and to express appreciation of the extensive facilities for research provided by the Coconut Research Board.

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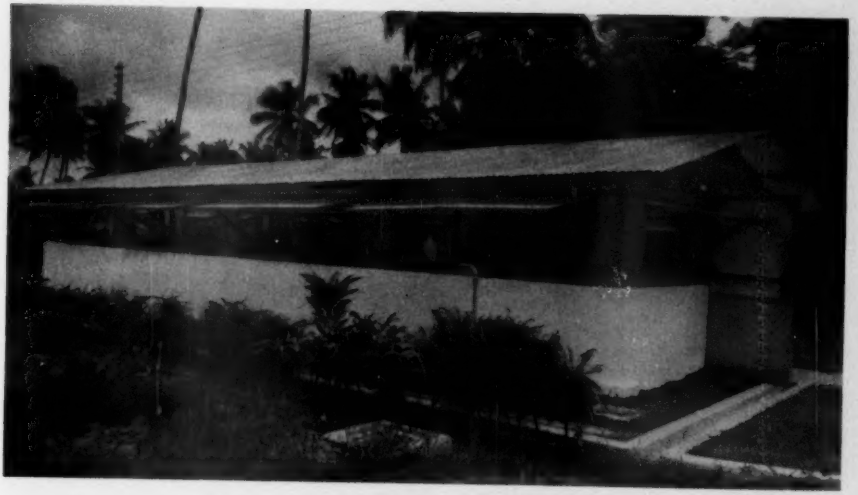

The 'Phytosolarium'

A NOTE ON THE INACTIVATION OF MOSAIC VIRUS IN CASSAVA (*MANIHOT UTILISSIMA* POHL.) BY HEAT TREATMENT

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WITH PLATES 2 AND 3

Summary

Cassava mosaic virus has been inactivated by growing infected cuttings at temperatures ranging from 35–39° C. for periods of 28–42 days. Treatment at 39° C. gave a greater proportion of healthy plants than treatments at lower temperatures, but fewer plants survived at the higher temperature. When green shoots produced during the heat treatment were removed immediately after treatment and rooted separately, they later gave healthy plants although their parent plants developed symptoms after some weeks in the greenhouse.

THERE are many records of successful inactivation of virus in infected plants by treatment with heat. Houtman [1] and Martin [2] freed sugar-cane from sereh and chlorotic streak viruses by immersing cuttings in water at 52° C. for 30 and 20 minutes respectively. In 1936 Kunkel [3] showed that peach-trees could be cured from yellows virus if kept at 35° C. for a fortnight or more, and in 1941 the same worker [4] freed periwinkle from asters-yellows using similar high-temperature treatments. Later, Kassanis [5] freed potato tubers from leaf-roll virus by keeping them in a moist atmosphere for periods of 10 to 20 days at 37° C. and in 1954 he demonstrated [6] that heat-therapy was effective in freeing infected plants from some heat-stable viruses such as tomato bushy stunt and cucumber mosaic.

This note describes the effect of various high-temperature treatments on the inactivation of cassava mosaic virus in the growing plant, carried out at Ibadan, Nigeria.

Materials and Methods

Experiments were first conducted on the effect of immersion of cuttings for varying periods (15 mins. to 3 hours) in water at a temperature of 50 to 52° C. but none of these treatments was successful in inactivating the virus.

The form of incubator used in the experiment described in this paper is based on that of Kassanis [6] and is of approximately the same dimensions (27 cu. ft.). There were some slight modifications, such as double-glass sides for better insulation and the use of a toluol regulator for controlling the heaters, and it was found more convenient to mount the fan upright at the end of the chamber instead of vertically on the roof ridge. The temperature recorded in the chamber did not vary more than ±1° C. of the set figure, and relative humidity was maintained between 70 and 85 per cent. by placing a flat dish of water in the chamber.

[Empire Journ. of Exper. Agric., Vol. 27, No. 105, 1959.]

Five boxes 1 foot square were accommodated in the incubator and these were kept watered from a container therein. The contents of the incubator were sprayed with a copper fungicide at 3-day intervals (Fig. 1, Plate 2), to prevent the development of moulds and other fungi.

The planting material used in all the experiments was derived from a hybrid variety of cassava, CCH7, maintained in a collection plot at Ibadan. After being planted in the boxes (twenty-five per box) the cuttings were placed in the incubator or as controls in the greenhouse.

The treatments were carried out at three temperatures: 35, 37, and 39° C. over periods ranging from 1 to 6 weeks. Growth was much retarded in the treatments at 39° C. and many of the cuttings died. At all three temperatures the leaves produced were smaller than the controls and they had a slightly greater length:breadth ratio.

After treatment the surviving plants were transferred in pots to an insect-proof greenhouse. Six weeks later those plants which were still symptomless were tested for freedom from virus by transmission tests using the method described by Storey and Nichols [7]. From 50 to 100 healthy Bemisia were caged on the stem apex of each plant for 24 hours and then transferred to young healthy cassava seedlings for a further period of 24 hours. Infected seedlings showed symptoms within 1 month but those that did not were kept under observation for a further period of 10 weeks to ensure that no transmission had occurred.

Results

With all treatments lasting 14 days or longer the plants lost all visible symptoms of mosaic from their leaves. However, symptoms soon reappeared (within 6 weeks) in the greenhouse on those plants which had been given an inadequate heat treatment. Table 1 shows the number of plants that remained healthy after treatment for various times at the three temperatures, and Fig. 2 (Plate 2) compares plants cured by treatment at 39° C. for 42 days with untreated controls.

TABLE 1. *The Relationship of Time to Inactivation of Mosaic Virus in Infected Cassava Plants at 35, 37, and 39° C.*

	35° C.		*37° C.*		*39° C.*	
Length of treatment (days)	*No. of plants survived*	*No. of plants healthy 16 weeks after removal from incubator*	*No. of plants survived*	*No. of plants healthy 16 weeks after removal from incubator*	*No. of plants survived*	*No. of plants healthy 16 weeks after removal from incubator*
7	25	..	25	..	25	..
14	25	..	25	..	22	..
21	25	..	23	..	19	..
28	20	..	23	..	14	2
35	18	..	15	..	10	4
42	18	1	12	2	8	4

Plants were considered to be healthy when it was not found possible to transmit mosaic with Bemisia as a vector. Three plants (all after treatment at 37° C. for 5 weeks) which remained symptomless were proved to be infected by transmission tests with the insect vector.

It was possible that even with some of the milder treatments (i.e. at the lower temperatures or for short periods at the higher ones) the virus was completely inactivated in the young green shoots but that a more severe treatment was required to inactivate the virus in the woody cutting. A technique was accordingly developed in which the soft green shoot was cut off 3 to 6 weeks after sprouting, treated with hormone (5 p.p.m. indolyl-butyric acid and 5 p.p.m. α-naphthalene acetic acid), and then rooted in an open well-drained medium consisting of coconut fibre and sand. This treatment produced a vigorous root system 3 weeks later (Fig. 3, Plate 3).

The young green cuttings obtained from plants in the greenhouse would not stand the high temperatures of the incubator for more than 10 days. On the other hand, similar cuttings taken from plants in the incubator became successfully established in the greenhouse at normal temperatures, and usually developed into healthy plants (Fig. 4, Plate 3). The results are shown in Table 2.

TABLE 2. *Inactivation of Cassava Mosaic Virus in Young Green Shoots excised from Infected Plants maintained at 37° C. and 39° C. for 4 and 6 weeks*

Temperature	*Time for which infected plants were grown in the incubator before removal of the green shoots*	*No. of green shoots removed*	*No. which rooted successfully*	*No. of shoots healthy 16 weeks after removal from parent plant*
37° C.	4 weeks	50	35	4
	6 weeks	46	32	9
39° C.	4 weeks	36	24	15
	6 weeks	30	12	12

A comparison of the results from Tables 1 and 2 shows that a greater percentage of healthy plants can be produced by striking cuttings from the green shoots after heat treatment than by keeping the treated plant as a unit. However, the treatment at 39° C. is so severe that most of the young green shoots died, and it was possible to establish only a very few from plants treated for 6 weeks. Whole plants which showed no visible signs of growth after 6 weeks (because their green shoots had died) frequently produced new growth in the greenhouse. Healthy-looking plants produced by both sets of treatments were susceptible to reinfections with mosaic virus introduced by the white-fly vector.

Nothing is known yet about the properties of cassava mosaic virus. (Lefèvre [8] claims to have transmitted virus by sap inoculation but Storey and Nichols [7] in East Africa, and the author, have been unable to confirm this.) Bawden [9] has demonstrated that some viruses with low temperature coefficients of thermal inactivation can be inactivated by heating infective sap for a few hours at temperatures much below their thermal inactivation points and Kassanis [6] has suggested that failures to free plants from potato virus Y and henbane mosaic virus by heat treatment might be partly due to their large temperature coefficients of thermal inactivation.

The success of the heat treatment in curing mosaic-infected cassava cuttings suggests that cassava mosaic virus itself has a low temperature coefficient of inactivation. In East Africa the existence of several strains of cassava mosaic virus has been demonstrated by Storey and Nichols [7] and a similar situation almost certainly holds in Nigeria, where plants of the same clone may display varying degrees of chlorosis and distortion of the leaves. There is a possibility that some strains or groups of strains may be more susceptible to heat treatment than others. Such a difference could explain the persistence of the virus in some plants which remained infected after treatment in conditions that cured other plants.

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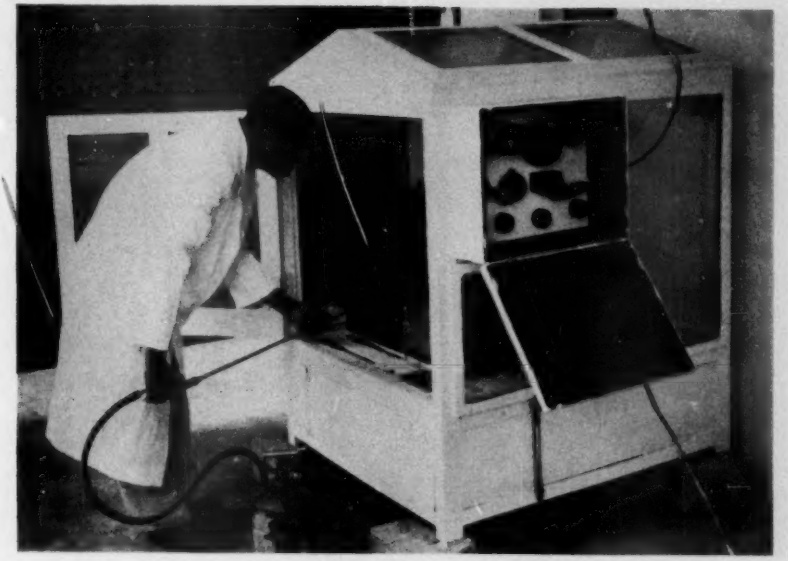
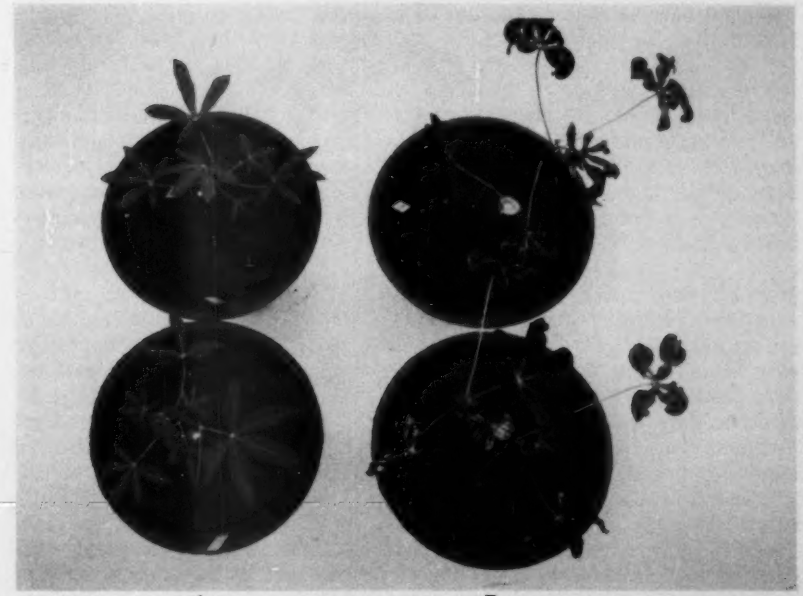


FIG. 1. Incubation chamber: spraying with copper fungicide to prevent the development of fungi



A B

FIG. 2. A. cuttings treated at 39° C for 42 days
B. cuttings untreated, i.e. grown in the greenhouse at normal temperatures

FIG. 3. Root development of green cassava shoots three weeks after removal from the parent cutting

FIG. 4. Healthy plants produced from green shoots excised from the parent plants after treatment at 39° C for 42 days

THE HEDMARK SYSTEM FOR PROGENY TESTING OF DAIRY BULLS WITH SPECIAL REFERENCE TO ARTIFICIAL INSEMINATION

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WITH PLATE 4

Summary

In order to combine the comparatively low expense of the field method for progeny testing of dairy bulls with the possibility offered by the station method as to information on characters other than milk and butterfat yield, a new method has been developed. According to this method the daughters of the bulls stay with their owners, and additional data are collected from a representative area by special assistants.

This method has been tried by the Norwegian Red and White Cattle Society from the autumn of 1955. The results of this trial are discussed.

THE development of artificial insemination has greatly increased the interest in progeny testing. New methods for progeny testing, with special regard to testing of A.I. bulls, have been developed. The main reasons for proposing new methods have been to improve the accuracy of the test, and also to get information about characters other than milk and butterfat yield.

In order to improve the accuracy of the progeny test, two different ways have been chosen. In one of these sire indices are calculated from the yield data of the ordinary milk records of the bulls' daughters. The development of population genetics has made it possible to eliminate many important sources of error, thus getting sire indices that give good estimates of the genetic value of the bulls. One of the most advanced sire indices is the one used by the Milk Marketing Board in England and Wales [1].

The other way of improving the accuracy of the test that has been tried is the one chosen in Denmark. Here a series of special progeny-testing stations have been set up. Each can hold about twenty daughters of one or more bulls, and their yield is measured under accurately standardized conditions of feeding and management. The bulls can thus be compared directly by the averages of their daughters' yield without reference to that of their own mates. This presupposes, however, that the average genotype of the dams of each group of daughters is the same.

In order to make correction for age and month of calving unnecessary, only heifers that are between 27 and 33 months of age, and calve between 20 September and 15 November, are accepted.

The accuracy of the field method and the station method were compared and discussed by Robertson and Mason [2] and by Hofmeyr [3]. The former authors compared the tests carried out at special stations

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(average seventeen daughters per bull) with tests in high-yielding herds (twenty-seven daughters on the average) in their accuracy of prediction of the performance of bulls in the poorer herds. The field test was slightly (but not significantly) superior for both milk yield and fat content. The repeatability of the station tests in the field was not good. The regression of field results on station test was only about 0·2 in herds at all production levels. Hofmeyr found that a field test on thirty-five daughters would seem to provide as reliable information on a sire's breeding value as a station test on eighteen daughters. According to the investigation of Robertson and Mason a group of thirty daughters in the field should give information on yield equivalent to that obtained from twenty daughters at the test stations, and would probably be superior so far as the fat content is concerned.

According to these investigations there is no need to choose the station method to improve the accuracy of the progeny testing of dairy bulls. As to the possibility of collecting data not on the ordinary milk record, the station system has doubtless great advantages. On the stations the farmers also get excellent demonstrations of feeding and management.

As to the cost, the station method is at a great disadvantage, and in a country like Norway which has from two to three times as many cattle breeds as Denmark but only one third of their number of cows, it would be impossible to finance a scheme for testing enough bulls by the station method. In order to combine the comparatively low cost and high accuracy of the advanced field method with the possibility offered by the station method as to information on characters other than milk and butterfat yield, the authors have devised a new system for progeny testing of dairy bulls. This is called the Hedmark System, after the Norwegian county Hedmark, where it was first tried in practice. This paper gives a description of the system and an account of the first practical trial of progeny testing by this system.

The Hedmark System

According to this system the bulls' daughters stay with their owners, and the additional data are collected from a representative area by special assistants.

The representative area should be placed in a district with good communications and as many cows per herd as possible. Artificial insemination should also be in common use, and most of the cows should be milk-recorded. In this way it is possible to get a large number of daughters of test bulls within a limited area. This is necessary in order to keep down the cost of the test to a moderate level and facilitate the organization.

The size of the representative area is limited downwards by the necessary number of daughters, and upwards by the cost. The upper limit may depend on the extent to which collection of additional data through the ordinary milk records is made possible.

Only heifers should be included in the test. In order to eliminate sources of error, only heifers that calve within a limited period are

included. If it is possible, without reducing the size of the groups too much, heifers whose ages diverge much from the mean may also be excluded.

Collection of Data

The milk and butterfat yields are entered on the ordinary milk record. When sampling milk for analyses of fat content, the recorder should make the samples sufficiently large to allow analyses of protein content too. In order to indicate that not only fat content but also protein content has to be determined, the bottles of milk samples from the heifers included in the progeny test are distinctively marked. Each heifer included in the progeny test gets a form which is placed in the ordinary milk-record journal. The milk recorder puts the recorded data on this form when he enters them in the journal. The milk and butterfat yields are added up and the mean fat and protein percentages are calculated per standard lactation year (300 days from calving).

The milking characters of the cows are measured by special assistants travelling from farm to farm. To reduce the error of measuring, the milking machines on every farm with test cows should be adjusted to operate at the same pulsation rate and vacuum level. Details about measuring milking characters under field conditions have been given by Sandvik [4] and are discussed later in this paper.

When the assistant visits a farm, he also scores the daughters according to a special system and takes a series of body measurements. Special attention should be paid to udder and teats. The assistant also inspects the journal, checks all doubtful data, and discusses them with the owner, the herdsman, and the milk recorder. He also ensures that dates of all heat periods and of all inseminations are noted on the form. In co-operation with the herdsman he scores the heifers for strength of heat, for temper, and for appetite.

The station method gives an excellent demonstration of the type of each progeny group, which is of great interest for the breeders. The other systems do not offer such an opportunity for the breeders to make themselves familiar with the progeny of the A.I. bulls they are using. In order to remedy this it is proposed to have a special show of a representative number of daughters of each bull at the end of the test. At this show the results of the test may be presented by means of tables and graphs, and the conformation of the daughters may be demonstrated.

Experience from Practical Trials with the Hedmark System

The Norwegian Red and White Cattle Society showed great interest in the system and provided the funds needed to get it tried in practice.

The first test started in the autumn of 1955. The neighbourhood of the city of Hamar in the county of Hedmark was chosen as a test area. The size of this area is approximately 2,450 square kilometres. The total number of cows is about 16,000; 63 per cent. of these are milk-recorded and about 55 per cent. inseminated artificially.

In the first year 12 bulls, with a total of 349 daughters, were tested. The daughters were distributed among 204 herds, and in 1955 the average butterfat yield of these herds was 171 kg. According to Mason and Robertson [5] this high level of production must be favourable for the accuracy of the test.

The number of cows within the test area, however, was not large enough to permit an accurate test of all bulls involved. This was especially the case with the milking characters, these being measured only when two or more test cows were in the same herd. The reason for this was the need to get as many cows as possible tested at reasonable expense. The milking characters were registered by continuous weighing of the milking machine bucket, with weight readings at half-minute intervals. The first year a specially constructed platform balance was used for the weighing (Fig. 1, Plate 4). This balance worked excellently, but it was so heavy that a vehicle was needed to transport it from farm to farm.

A total of 226 cows were measured morning and evening two or three times during the first 230 days of lactation. It is, however, preferable not to measure later than the first 150 days of lactation.

In order to get more daughters of each bull included in the test, the work of measuring the milking characters was altered in the second-year test. At a short course, the milk recorders in the district were instructed in taking the measurements which were to be carried out when they visited the farms to record the milk yield. This visit takes place once every three weeks.

Many of the milk recorders travel by bicycle, and therefore the platform balance could not be used. The spring balance used in the ordinary milk recording, however, is also usable for the continuous weighing of the milking machine bucket. At first, the balance was fastened to the ceiling by a hook and chain. This was not quite satisfactory, however, as it did not allow the machine bucket to move with the movements of the cow. To remedy this, a special stand for the balance was constructed by Osm. Sandvik, teacher at the Rogaland Agricultural School, Öksnevad (Fig. 2, Plate 4).

In the first year the protein content of the milk was determined by the Kjeldahl method. This method, however, is too expensive, and if the protein content of the milk is to be determined in future, one of the newly developed short-cut methods with sufficiently high accuracy will have to be used.

In order to obtain preliminary information on the progeny groups, the form for each cow was collected after 200 days of lactation. It was easy to calculate the group means from the different data obtained and to carry out statistical analyses with the observations set up in this way. The method had a serious disadvantage, however, compared with the station method, as it was not possible to collect the forms often enough to get preliminary information. To correct this drawback an attempt will be made to work out a system that may be used by the milk recorders in reporting the recorded data to the breeders' society. In this way the bulls may be ranged according to peak yield, the 100-day yield and the

200-day yield, as soon as possible. It is very important that this can be carried out in a practical way, with as little additional work as possible on the part of the milk recorders.

When the group averages of the 200-day data were calculated, ten representative daughters of each bull were shown at a special show in Hamar. The results of the test were printed in the catalogue [6] and they

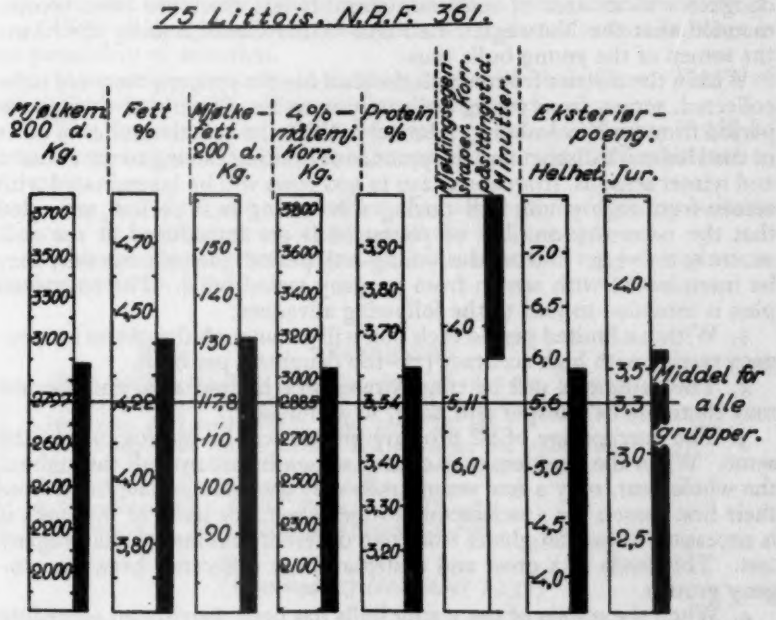

FIG. 3. Graph illustrating the results of the progeny test for a single group.

were also illustrated by means of graphs for each group of daughters (Fig. 3). From the left the different columns show: (1) kilogrammes of milk in 200 days; (2) fat per cent.; (3) kilogrammes of butterfat in 200 days; (4) kilogrammes of fat-corrected milk in 200 days; (5) protein per cent.; (6) corrected machine time; (7) score for conformation; (8) score for udder. The horizontal line crossing the scale represents the average for all groups.

The amount of genetic improvement per annum resulting from artificial-insemination breeding depends chiefly on the length of the generation interval, the accuracy of progeny testing of the bulls, and the extent to which a selection amongst the progeny-tested bulls is possible. As shown by Skjervold [7] the genetic improvement will be four times as great when the best two out of twenty progeny-tested bulls are selected to breed the the next generation, compared with the improvement obtained when

the best two of four progeny-tested bulls are selected. It is, therefore, necessary to introduce a great number of young bulls (1 to 2 years old) at the A.I. centre every year. It then becomes necessary to collect the data for the progeny test from a comparatively wide district in order to get a satisfactory number of daughters in each progeny group. By distributing the semen from the young bulls according to a special plan, however, it should be possible to concentrate the necessary number of daughters in an area of moderate size. It has therefore been recommended that the Norwegian Red and White Cattle Society distribute the semen of the young bulls thus:

Within the district from which the data for the progeny tests are to be collected, semen from young bulls only is to be distributed during the period from 15 November to 1 January. With the actual number of cows in the Hedmark district and the practice of limiting calving to the autumn and winter seasons, from about 250 to 300 cows will be inseminated with semen from each young bull during this 'young-bull period', provided that the necessary number of young bulls are introduced at the A.I. centre every year. During the 'young-bull period' picked cows only may be inseminated with semen from progeny-tested bulls. The suggested plan is intended to lead to the following advances:

1. Within a limited period each bull will get enough daughters for progeny testing with high accuracy (75–100 daughters per bull).
2. The daughters will be concentrated in a limited area, and the test may therefore be cheaper and easier to administer.
3. The average age of all progeny groups will be approximately the same. When the breeders may choose semen from any bull throughout the whole year, only a few young bulls may get enough daughters from their first season for a satisfactory progeny test; for most of the bulls it is necessary to use daughters from two different seasons for the progeny test. This leads to a great and systematic age difference between progeny groups.
4. When the semen of the young bulls has been distributed according to this plan, it will be possible to 'progeny-test' many bulls one year earlier than when the free choice of bulls is practised the whole year. This is especially the case when the calving time is limited to a shorter period, as is the case in most districts in Norway.

As to the accuracy of the method, this cannot be investigated before it has been in use for some years. On the basis of the authors' experience so far, the advantages and disadvantages of this method, as compared with the station method, may be summed up as follows:

Disadvantages

1. Some daughters in the field may get unsatisfactory feeding and management, and may, for this reason, be unable to express their potentiality fully.
2. Lower accuracy of the yield data because of longer record intervals.
3. It is not possible to get preliminary information to the same extent as by the station method.
4. No demonstration of feeding and management.

Advantages

1. The cost is only about 20 per cent. of that of the station method.

2. The daughters of every bull are distributed randomly among a large number of herds, the effects of differences in feeding and management being thus eliminated. As shown by Johansson [8] there are significant differences in the performance of the heifers at the different Danish stations.

3. Greater number of daughters per bull than with the station method.

4. With all daughters within the test area included in the test, there is no possibility of selection.

5. It is possible to compare the daughters with their dams. This is of special interest for the additional data so obtained.

6. The daughters may be tested for more years. In this way it will be possible to compare the different groups as to fertility and resistance to diseases.

7. The test does not depend on the possibility of getting suitable stations. It is therefore easier to get all the bulls tested.

A table giving the results from the bulls tested in 1955–6 is given as an Appendix (p. 66).

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APPENDIX

Results from the bulls tested in 1955–6

	Characteristics	88 Skjelve-Tor	75 Litlois	418 Veitakleiva	554 Hamra-Hero	Jälin	114 Kåns	116 Kåns	81 Litlois	67 Thiels	54 Pahuleml	234 Yli Lemu	243 Yli Lemu
Yield in 200 days	No. of daughters	25	18	21	26	16	57	58	15	32	14	48	19
	Milk yield, kg.	2,893	2,985	2,580	2,879	2,437	2,823	2,877	2,872	2,942	2,539	2,725	3,007
	Butter fat, %	4·09	4·41	4·31	4·30	4·55	4·03	4·05	4·12	4·08	4·22	4·27	4·19
	Butter fat yield, kg.	118·4	131·3	111·3	123·7	111·0	113·9	116·5	118·2	119·9	107·1	116·4	126·0
	S.D.	19·1	19·4	22·5	21·3	21·0	21·9	19·9	25·4	23·1	28·8	19·5	18·5
	Maximum daily yield of milk, kg. in average	17·4	18·0	15·9	16·9	14·4	16·8	17·0	16·9	17·2	14·8	16·8	17·6
Protein content	No. of daughters	21	15	19	24	13	30	31	15	24	14	37	15
	Protein, %	3·67	3·62	3·74	3·51	3·72	3·38	3·42	3·36	3·47	3·56	3·49	3·50
	S.D.	0·24	0·30	0·20	0·18	0·17	0·19	0·17	0·25	0·27	0·16	0·23	0·19
Milking characteristics	No. of daughters	18	15	17	20	12	27	31	9	13	21	30	13
	Corrected machine time, min.	5·27	4·29	5·13	4·63	4·70	4·50	5·19	5·78	4·79	4·70	5·18	4·37
	S.D.	1·18	0·96	1·75	1·41	1·06	1·08	1·63	1·88	1·69	1·49	1·09	1·13
	Corrected peak flow, kg./min.	1·77	2·11	1·99	2·12	1·93	2·11	1·85	1·74	1·94	2·03	1·78	2·05
	S.D.	0·401	0·547	0·551	0·622	0·429	0·505	0·445	0·614	0·508	0·767	0·363	0·462
Size and conformation	No. of daughters	21	17	20	24	13	51	49	12	30	12	42	16
	Heart girth, cm.	178	181	177	180	176	181	179	175	175	172	176	174
	S.D.	5·10	7·55	6·86	7·07	5·09	8·19	7·28	4·24	6·48	8·18	8·25	6·40
	Udder score, points*	3·1	3·6	3·3	3·1	3·4	3·2	3·2	3·6	3·0	3·5	3·4	3·5
	S.D.	0·65	0·48	0·55	0·60	0·46	0·52	0·58	0·67	0·59	0·64	0·61	0·53
	Thighs score, points*	3·4	3·4	3·0	3·5	2·8	3·5	3·4	3·0	3·2	3·1	3·3	3·0
	S.D.	0·46	0·61	0·62	0·41	0·66	0·52	0·62	0·62	0·57	0·48	0·55	0·65
	Rump score, points*	3·0	3·2	2·6	2·7	2·6	3·4	2·9	3·2	3·1	2·6	2·8	3·0
	S.D.	0·52	0·44	0·64	0·49	0·53	0·52	0·57	0·52	0·55	0·44	0·55	0·59
	Back score, points*	3·3	2·9	3·3	3·0	3·1	3·4	3·2	3·5	3·2	3·4	3·1	3·4
	S.D.	0·52	0·45	0·41	0·49	0·49	0·53	0·53	0·48	0·52	0·47	0·46	0·35
	Limbs and movement score, points*	3·3	3·4	2·7	2·9	2·9	3·1	3·0	3·0	3·0	3·2	3·3	2·8
	S.D.*	0·46	0·5	0·54	0·50	0·75	0·61	0·57	0·56	0·57	0·50	0·64	0·61
	Total conformation score, points†	5·8	5·9	5·1	5·4	4·9	6·2	5·6	5·7	5·6	5·7	5·5	5·5
	S.D.	0·78	0·97	1·07	0·94	0·98	0·92	0·97	0·75	0·86	0·78	0·94	0·99
	Length of front teats, cm.	5·4	5·1	5·0	4·9	5·2	5·3	5·7	5·5	4·9	5·2	5·2	5·3
	S.D.	0·85	0·60	0·69	0·76	0·79	0·72	0·83	0·57	0·99	0·84	0·75	0·62
	Length of hind teats, cm.	4·6	4·3	4·2	4·1	4·2	4·3	4·6	4·8	4·2	4·5	4·4	4·4
	S.D.	0·65	0·63	0·60	0·59	0·82	0·69	0·53	0·45	0·79	0·99	0·54	0·55
	Distance teat points–floor, cm.	54	52	50	52	52	53	52	50	54	48	52	52
	S.D.	3·08	2·26	3·11	3·37	3·38	2·88	3·11	2·24	3·41	4·17	3·08	2·24

S.D. = standard deviation. * Top score 5 points. † Top score 10 points.

FIG. 1. Platform balance for continuous weighing of the milking-machine bucket

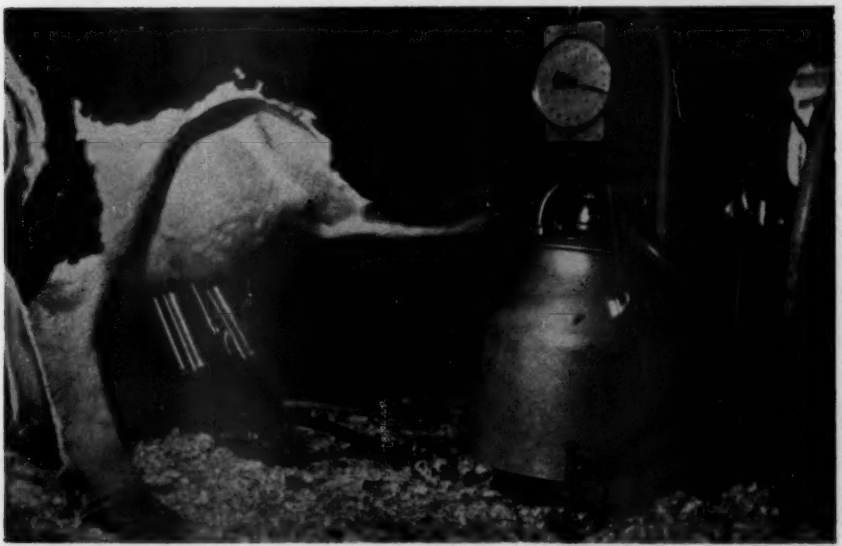

FIG. 2. Stand for spring balance

FURTHER INVESTIGATIONS INTO THE 'CAPE ST. PAUL WILT' OF COCONUTS AT KETA, GHANA

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Summary

Disease symptoms additional to those already recognized are described and the effect of the disease on growth is discussed. The past spread and occurrence of the Cape St. Paul wilt and allied maladies are considered in some detail. Reference is made to the soil in the area, the ground water relationships, and mineral nutrition in relation to the disease. A summary is given of the pathological investigations and attention drawn to the failure to transmit the disease. Various theories regarding possible causes of the Cape St. Paul wilt and its relationships with the Bronze Leaf wilt in Trinidad are discussed. An account is given of further studies in progress and contemplated, including the study of possible resistance.

THE results of earlier investigations into the Cape St. Paul wilt of coconuts in the Keta district of Ghana (Map 1A) have been reported by Martyn [1] who, on the basis of his findings there and observations on the Awka disease in Nigeria, concluded that symptomatically both were the same as the Bronze Leaf wilt (B.L.W.) of the southern Caribbean, and he proposed that henceforth the two former be known by that name. The same writer [2], moreover, disagreed with the hypothesis given by Briton Jones [3] and accepted by Bain [4] that B.L.W. was due to unfavourable soil-water conditions, and he suggested that a cause related to the uptake of nutrients and onset of maturity be sought. Bull [5] agreed with this theory as regards the Awka disease in Nigeria, but both he and Martyn [1, 2] pointed out that the symptoms are not typical of a straightforward minor element deficiency. More recent work at Keta, however, does not support such a hypothesis and it is the purpose of this paper to describe briefly some of the results which have made it possible to discount many of the suspected causes of the Cape St. Paul wilt. No definite evidence has been obtained that the disease is of a parasitic nature nor, despite numerous attempts, has it been possible to produce symptoms in healthy palms by artificial means. The original outbreak of the disease is now known to have been a scattered one and the recent outbreaks likewise are discontinuous. It has also been shown that the disease incidence may be affected by vertical movements of the ground water, but not by changes in its salinity as Waterston [6] suggested.

Symptoms

The principal symptoms of Cape St. Paul wilt were described by Martyn [1]; briefly these are: nutfall; bronzing and collapse of the leaves from the oldest to the youngest; discoloration of the unopened inflorescences; the heart leaf dies usually within 3 to 5 months after nutfall. It should be noted, however, that symptom development in the disease at Keta is never reversible as it may be in the case of B.L.W. in Trinidad. 'Gum pockets' have been observed in the sheaths, leaf bases, and at the

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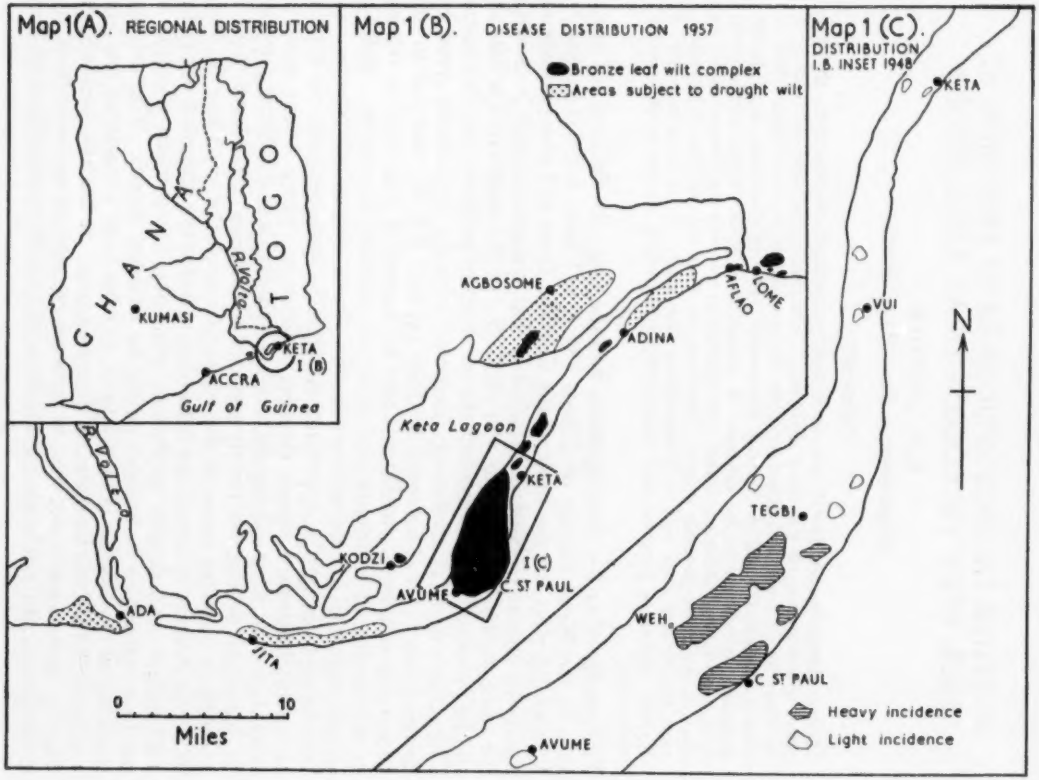
Map 1(A). REGIONAL DISTRIBUTION
GHANA
TOGO
R. Volta
KUMASI
KETA
I (B)
ACCRA
Gulf of Guinea
Map 1 (B). DISEASE DISTRIBUTION 1957
Bronze leaf wilt complex
Areas subject to drought wilt
AGBOSOME
AFLAO
LOME
ADINA
Keta Lagoon
R. Volta
KETA
KODZI
I (C)
AVUME
C. ST PAUL
ADA
JITA
0
10
Miles
Map 1 (C).
DISTRIBUTION
I.B. INSET 1948
KETA
VUI
N
TEGBI
WEH
C ST PAUL
AVUME
Heavy incidence
Light incidence

calyx end of the unripe nuts of young mature palms. Occasionally at the extreme base of the bole of such palms a 'brown rot' was noticed which may advance into and up the trunk; this, however, is never found in mature, hardened palms although these may occasionally show a slight rotting of the ground tissue at the point of emergence of the roots at soil level.

Examination of epidermal strips from leaves of diseased palms did not reveal the binucleate cells which Nutman and Roberts [7] considered to be characteristic of the 'Unknown disease' in Jamaica. Irrigation with iodine solution, of the split mid-ribs of green leaves from diseased palms, did, however, show more starch accumulation than in those from healthy palms. In this connexion it is interesting to note that no starch reaction was given by palms showing symptoms of severe waterlogging. It was also found that the sequence of 'nut fall' from cut bunches hung up in the sun was similar to that encountered on diseased palms in the field: that is to say all except the ripe dry nuts and unfertilized 'buttons' dropped in from 6 to 10 days. It should be mentioned that exudation from the stumps of freshly felled palms is noticeably greater from those which are apparently healthy than from those in an early stage of the disease. Despite numerous and detailed observations no evidence has yet been found that the primary symptoms may appear unilaterally as Leach [8] found with the 'unknown disease' and Meiffren [9] found in Togo in the case of the Kainkope disease.

Effect of the Disease on Rate of Leaf Growth

The effect of disease incidence on the rate of leaf growth was examined by comparative measurements according to the method described by Leach [8] in three contrasting plots (see Fig. 1). Plot A represents the leaf growth of those four of the eighteen 9-year-old palms in this plot which became diseased in January 1956; Plot B contained six 30-year-old palms which were apparently healthy and which remained so during the whole period in which measurements were made. Plot C contained twelve healthy 7-year-old palms, which were regularly watered throughout the year; it is noticeable that, as was expected from their appearance, the growth rate was higher. Palms vary considerably in the amount of growth which occurs after the appearance of the first symptoms and also in the time which elapses between the onset of the disease and the death of the heart leaf; typical examples are given in Table 1.

Distribution

In Ghana the disease has at present been recorded only between Ada and Aflao (see Map 1B), the heaviest incidence being in the Avume-to-Keta area where some 100,000 palms have died since the disease was first recorded at Weh in 1932. In 1940 an outbreak was reported from Ada but there is no trace of this today. A new outbreak in Ada has, however, recently been reported, and 'drought wilt' and flood damage are also seen in that area from time to time. The outbreaks at Kodji, Aflao, and Agbosome have all occurred during the last two years and although the symptoms differ slightly from those in the main disease area, they have many features in common and appear to be variants of the same disease.

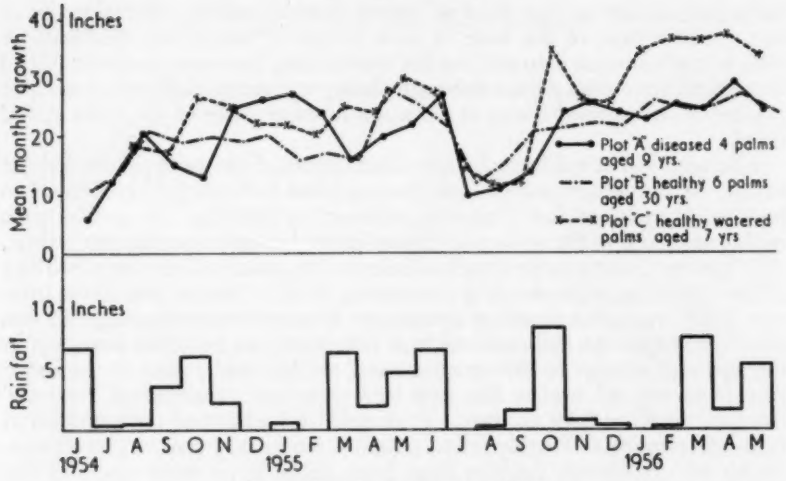

FIG. 1. Leaf growth and rainfall.

TABLE 1. *Monthly Leaf Growth in Inches and Onset of Disease*

Month	*Palm 1*	*2*	*3*	*4*	*5*
1954					
May	3·5"•	9·5"	7·5"•	9"	8"
June	11·0	12	8·5	24•	8
July	15	18•	D	0·0	5•
Aug.	D	9·5	..	D	12
Sept.	..	D	..	..	16
Oct.	..	..	..	..	19
Nov.	..	..	..	..	D

• = *Appearance of primary symptoms*
D = *Heart leaf wilted*

Map 1C brings out the significant fact that the early distribution was originally scattered through what is now a completely devastated zone, and this behaviour is repeated in the present easterly spread beyond Keta, where there are now isolated outbreaks separated from each other by several miles of healthy coconut farms just as in 1948 the area Avume to Keta contained discrete centres of infection. There is no evidence that the prevailing south and west winds are in any way concerned with the spread of the disease. The spread within a plot has been found to be random [6]; it has, however, been recorded that some groups of palms may start to show disease symptoms at the same time, whilst in others the initial outbreak starts from one or two isolated palms in different parts of the same plot. Once the disease has started, a block of a hundred or more mature palms will usually be devastated within 2 years, but there are areas where the disease exists in a chronic rather than

an acute form, notably along the foreshore and in and around the Government residential area at Keta.

There is, moreover, some association between proximity to the sea and decreased incidence of disease, as Table 2 illustrates.

TABLE 2. *Disease Incidence in Relation to Proximity to the Sea*

Distance from sea (yds.) .	100	200	300	400	500	600	700	800	900
% dead palms . . .	..	22	61	94	97	95	89	100	96

The above results were obtained in the Tegbi area during 1954 and this situation has since remained substantially unchanged despite the fact that the surviving palms are of the same age as those which have died and with which they were in direct contact. A possible explanation is discussed later when considering water relations and disease incidence.

Ecological Conditions and the Disease

In the areas under consideration other pathological conditions of coconuts occur, distinct from the 'wilt disease', and these are directly associated with unfavourable water relations. It is of some importance to distinguish these conditions from the disease, to examine the circumstances in which they arise, and to show as far as possible how they differ from those predisposing to the onset of disease.

The maladies affecting coconuts which are considered here occur in a restricted area of Ghana and Togo, in a region where the mean annual rainfall is of the order of 32 inches. It has been observed elsewhere [6, 9] that palms in such conditions of low rainfall are entirely dependent on ground water during the long dry season. It is therefore in those sections of the littoral where the water table is naturally low or subject to sudden fluctuations that a partial failure of the rains may bring about the death of a number of palms from drought. The areas where this type of wilting occurs are plotted in Map 1B which shows that the most severely affected area is the Agbosome district. Conversely, it is not uncommon for the lagoon-side palms to die from flood damage during and immediately after exceptionally wet seasons when the lagoon level rises above the normal and does not drop to its usual dry-season level for some months. This type of damage is typically found between Keta and Adina, where the littoral may be only 80 yards wide and at least 300 palms died due to flooding in 1955–6. Here the young, unhardened palms suffered especially, showing collapse and drying out of the leaves and flower stalks but without the brilliant, abnormal leaf coloration which is characteristic of 'Cape St. Paul wilt'; the symptoms were indeed similar to those described by Pandalai *et al.* [10] in India on palms around which peaty subsoil had been deposited.

The soils of the area consist mainly of alkaline marine sands which in most places retain their dunal undulations. There are extensive marshes in the Weh, Vui, and Agbosome districts and many smaller ones in the inter-dunal depressions between Cape St. Paul and Keta.

The lagoon flats, which are often underlain by a vermicular iron pan, are rarely planted with palms and will not be considered further. On the Agbosome side of the lagoon, sands again predominate and in places these may be very deep (18 ft.) and finer-grained than on the coastal strip; further inland Tertiary clay deposits are found, but coconuts are little grown on these. Along the coastal strip an unusual, calcareous hard-pan occurs locally [11] in the subsoil usually at, or about, mid-season ground-water level (4–6 ft.). In thickness it varies from ¼ in. up to a maximum of 18 in. The thicker pans are deposited as a multi-layered sandwich of cemented sand grains, shell fragments, and matted, decayed roots. As a rule, however, they are 2–3 in. thick, assuming in the dry season the hardness of concrete and are impenetrable by plant roots. During the periods when the water falls below the pan level the palm roots are cut off from all water except such as can be obtained from the top soil; this soon dries out and the palms may be dependent on the capillary water for as much as 3 to 4 months of the year. Above the pan, or ground-water level, iron-staining and manganese concretions are common especially in the Weh area. The root system of the palms growing over the hard-pan is characterized by a thick layer of feeding roots in the first few feet of the soil profile, a zone of about 2 ft. below this containing a few vertical roots which become much branched and deflected on reaching the pan. These roots are black, thin, and profusely matted, with an extremely thick and brittle outer layer; an identical root system has been described from Trinidad [4] on diseased palms growing over an intolerant marl layer.

In Ghana there is evidence that the pan thickness is increasing as a result of the accumulation of successive generations of palm roots which, especially in the 'sandwich' type of pan, become covered over with a layer of calcareous material and ultimately perish. In some instances it was noted that the depth of pan was influenced by the quantity of roots above it, i.e. the nearer the bole the thicker was the pan; immediately beneath it was 12 in. thick, at 8 ft. radius, 5 in., and at 14 ft. only 3½ in. This might indicate that the older palms are further removed from their water supply. But although the peak of the disease is reached in March/April [6] when the ground-water level is at its minimum, plots of palms watered regularly through the dry season still died from the disease, indicating that water stress was not the sole cause.

The ground water is mainly dependent upon the seasonal rainfall; even very high tides affect the water level up to only 400 yards inland in the devastated area; a diurnal movement of a few inches at the beach has been recorded at Adina. There is no measurable water movement in the upper layer of the water table from the lagoon to the sea, nor vice versa, in the widest section of the littoral, although the lagoon lies below mean sea-level. Rainfall is thus the predominant factor affecting the height of the water table, and the levels between wet and dry seasons may differ by as much as 3 ft. During the dry season the ground water is consequently static, but in the wet season its level rises and seepage takes place from the periphery of the catchment area.

Contrary to expectation [6] it has been found that the changes in

salinity of the ground water are not great enough to cause the death of the palms, which can in fact tolerate changes in concentration of total chlorides of as much as 8,000 p.p.m. through the year and will yield well where the concentration reaches 20,000 p.p.m. at some times during the year; though stunted and barren they will continue to live with concentrations as high as 43,000 p.p.m. [12]. Moreover, the wilt disease incidence has been greater so far in the wider part of the littoral where the water is fresher than in the narrower sections where high salinity conditions exist.

Nutrition in Relation to the Disease

The first diagnostic symptom is 'nut fall', which is not preceded by any noticeable decline in growth rate such as would follow an acute deficiency of either a major or a trace element involved in cell division (see Fig. 1). Field observations show that both high- and low-yielding palms are susceptible, e.g. a plot of regularly spaced palms at 69 per acre which were heavily manured with cow dung succumbed to the disease as rapidly as a plot of unmanured, irregulary planted palms at a density of about 160 per acre. Palms around which sheep or cattle are tethered may bear as many as 80–100 nuts per tree whereas the district average is around 40; but as Forbes [13] has shown, the distribution of the disease is unaffected by the presence or absence of human habitations.

It was to be expected, therefore, that the application of organic or inorganic manures would have little, if any, effect on disease incidence and this has been found by experiment to be so. In a series of trials to investigate this point, up to 300 lb. of cow manure or 10 lb. of inorganic fertilizer per palm were applied, or in trenches between the palms, or forked into the surrounding top soil, or mixed with soil and moulded to a height of 3 ft. around the trunk. Such treatments neither prevented nor cured the disease.

The possibility of the disease being due to a trace element deficiency has been suggested [1, 2, 5] and several simple trials have been carried out at Keta [14]. These showed that no control followed application to the soil of borax and manganese sulphate, singly or together, at annual rates of up to 1 lb. of the former and ¾ lb. of the latter per palm. Some of the palms contracted the disease before the treatments could have produced any effect, but one trial, which had remained healthy for 2½ years, has now succumbed.

Foliar applications of trace elements were also tried, using dilute solutions of copper, manganese, magnesium, iron, zinc, and molybdenum compounds, and, in particular, borax, sprayed on to the leaves in 6 successive months. This also proved ineffective in preventing the disease since all the palms died within 8 months. Foliar analysis, however, showed that a negligible quantity of the applied elements had been absorbed. Borax, although applied as a 0·25 per cent. solution, did not in fact increase the boron content of the leaf tissue.

The final and most efficient method of application attempted was implantation of solid reagents in the trunk, using all the elements both singly and together in one application. Dosage rates were similar to

those recommended by Innes [15] in Jamaica; but as zinc, copper, and molybdenum were found to result in slight leaf scorch these rates were reduced in a subsequent trial. When foliar analyses for boron, copper, and manganese on these palms were carried out 4 months after injection, the results confirmed that there had been a substantial uptake of these elements. Thus boron increased from 11·7 to 16·6 p.p.m.; copper from 5·6 to 10·2; and manganese from 88·1 to 337·0. Nevertheless, 15 months after the trials were started, over 50 per cent. of the palms had died and there was no indication that any element was exerting a controlling effect. It was in any case unlikely that there would be any response from manganese as the leaf content of this element in palms in the diseased zone had been found to vary from a mean of 88 up to 190 p.p.m., whereas the limits of adequacy for manganese are stated to be between 10–20 p.p.m. leaf dry matter [15]. The higher leaf content of manganese occurred over subsoil containing manganese concretions.

Pathological Investigations

In conjunction with the foregoing physiological studies many attempts were and are still being made to observe and isolate a possible pathogen. A number of fungi have been isolated (Table 3) but, as has been the experience of other workers on similar maladies of coconuts, none appears to be the causal agent of the disease.

TABLE 3. *Fungi Isolated from Diseased Coconut Tissue and Rhizosphere*

Section	*Isolates*
Crown tissues	*Diplodia palmarum*; *Penicillium* sp.; *Pestalozzia palmarum*; *Thielaviopsis paradoxa*.
Trunks (standing)	*Acrothecium* sp.; *Diplodia palmarum*; *Gliocladium roseum*; *Helminthosporium* sp.; *Penicillium citrinum* and spp.; *Thielaviopsis paradoxa*; 137/P/1.
(rotten)	*Ganoderma curtissii*; *Pleurotus* sp.; *Polystictus sanguineus*.
Roots	*Absidia Butleri*; *Aspergillus niger* and spp.; *Cephalothecium* sp.; *Chaetomium murorum*; *Cladosporium* sp.; *Diplodia palmarum*; *Fusarium* sp.; *Giberella fujikuroi*; *Gliocladium roseum*; *Pithomyces* sp.; *Thielaviopsis paradoxa*; *Tilachlidium* sp.; 107/P/1.
Soil	*Acrothecium* sp.; *Aspergillus* spp.; *Chaetomium mororum*; *Curvularia maculans*; *Diplodia palmarum*; *Fusarium solani*; *Helminthosporium* sp.; *Neocosmopara vasinfectum*; *Penicillium* spp.; *Pythium* sp.; *Thielaviopsis paradoxa*.

The limited attempts to isolate soil fungi were made using Warcup's [16] soil plate method and Waksman's special media. The genera isolated are incidentally very similar to those obtained by Radha and Menon [17] in India in their studies of the rhizosphere of wilting palms there. The unidentified sterile isolate 137/P/1 grew out of the clean ends of the dry, rotted tips of primary roots incubated in a moist chamber; and it was also at the margin of the brown rot in the trunks of immature and soft-stemmed palms. *Thielaviopsis paradoxa* was isolated from all

parts of diseased palms, but Fusaria were not found so frequently at Keta as in Togo [9]. Numerous bacteria developed from root and trunk isolations and although some of these and the more consistent fungal isolates were reinoculated into healthy palms a year ago, no disease symptoms have yet appeared. Eelworms have not yet been found to be associated with the disease.

During the past four years no positive result has been obtained from any transmission trials carried out at Keta using the following inoculation methods: seedling palms were grown in soil taken from a diseased area; large quantities of roots, leaves, and trunks of diseased palms were buried annually around seedling and mature palms; pegs of tissue from the trunk and leaves of palms in all stages of the disease were inserted into the corresponding part of healthy palms; sap from diseased buds and leaves was inoculated into the nuts, into the heart leaves of seedlings, and into the leaf bases of young leaves on mature palms; rotten bud tissue mixed with damp sawdust was stabbed into the 'spear' of mature palms; a 'sandwich' of diseased leaves and young leaves of healthy mature palms was held together and cut through with a cutlass to promote transmission and, on some of the same palms, the top sections of trunks and leaves of diseased palms were tied to the heart leaves. A few of these trials failed because the disease killed all the treated and control palms. Others are still continuing but only 15 out of the 189 treated palms have died compared with 12 of the 147 controls.

A further trial in progress concerns the possible relationship of the numerous Rhinoceros beetles (*Oryctes monoceros* and *O. owariensis*) and the disease; this is being carried out in large insect-proof cages. Since earlier experience showed that immature healthy palms transplanted from a low-lying disease area to slightly higher ground remained healthy, whilst those in the original plot died, an experiment has been laid down with well-grown seedling palms planted in large drums with a small drainage outlet. Some of the palms are watered with ground water from a disease area and the remainder with water from a healthy one; it is hoped that this trial will settle the question whether the ground water carries a parasitic or toxic factor without the results being complicated by death from waterlogging. Other trials are in progress to show whether cassava 'white thread' disease (*Fomes lignosus*) has any bearing on the disease or whether it is incidental, since it has been noted that strands of white mycelium are often found on the surface roots of diseased palms.

Finally, the possibility of resistance has not been overlooked and seedlings have been raised from nuts of the few surviving palms in the worst affected area and these have been planted out for observation in plots together with dwarf palms from Malaya.

Discussion

It was shown from observations on the disease symptoms that the first indication that a palm is affected by Cape St. Paul wilt is the occurrence of 'nut fall', and that leaf growth continued until the disease was well advanced. The causal agent therefore does not apparently directly affect

the meristematic tissues as would probably be the case with a trace-element deficiency. On similar grounds and as a result of fertilizer trials the question of a major-element deficiency can be dismissed since any palm over about 5 years old will die at approximately the same time irrespective of its spacing, vigour, or the fertility status of the soil. It must therefore be concluded that the nutritional hypothesis [1] put forward to explain the death of the palms at Keta is no longer tenable.

The question of a parasite must now be considered and, whilst it is admitted that the failure to isolate a possible pathogen is inconclusive evidence that the disease is not due to fungi or bacteria, the inability to transmit the disease by the many and diverse methods already tried at Keta does not suggest a soil-borne or trunk-invading parasite. Furthermore, the scattered distribution over the entire area and its random occurrence within plots argue against contact or windborne infections in the first instance. The evidence from leaf growth and the sequence of leaf symptoms from old to young render a virus hypothesis improbable; moreover, in considering a disease of that nature it is very difficult to reconcile the distribution and observed disease gradient inland from the beach with the fact that the farms were continuous and thus presumably subject to the same insect infestations; visibly so in respect of scale and Rhinoceros beetle.

It is now necessary to discuss the soil–water relationships and see whether the findings from Trinidad [4] can be reconciled with the facts at Keta, or whether it is legitimate to dismiss them *in toto* [1, 5]. First, as mentioned above, the symptoms suggest a cause related to the soil or ground water and it seems logical to work on the assumption that the answer to the Keta disease ought to be found in the soil, roots, or lower part of the trunk. The salinity of the ground water has been shown not to be the cause, but it was noted that the disease was much more intense at a little distance from the shore. However, the only measurable difference detected between the seashore and the inland devastated sections was in the vertical ground-water movements, which in the former fluctuated more than in the latter. It is inland also that the calcareous hard-pan chiefly occurs although it must be admitted that it also occurs in some areas where the disease is at present unknown. It was further demonstrated that a water shortage was not the prime cause even where the accumulating pan came between the roots and the ground water. At Keta the symptoms due to flooding are a collapse of the crown, whereas if the subsoil only is waterlogged, symptoms very similar to those of the disease are produced. It suggests itself therefore that though it is neither a shortage nor excess of water causing the disease, yet the water may in some way be the cause or carrier of the disease.

At Agbosome the disease is localized in and around a low-lying area of fertile, black alluvial soil with high water table. Here the disease has already killed most of the very vigorous 15-year-old palms; a sample survey in 1956 through the lowland and adjacent upland area showed that 57·7 per cent. were affected in the former compared with 7·3 per cent. in the latter. The symptoms are slightly atypical in respect of 'nut fall' and degree of drying out of the leaves, but they are so similar to

those at Keta that it must be considered to be allied to the Cape St. Paul wilt. It seems highly probable that the disease here is due to the unfavourable soil conditions which in fact correspond to the widespread Class 1 wilting soils in Trinidad: 'Surface soil is close textured and overlies a subsoil which is impervious to water. Such a soil is subject to waterlogging during wet periods and liable to dry out quickly during periods of drought' [4, p. 27].

It is therefore concluded that a Bronze Leaf wilt can be induced by certain soil-water conditions, in this instance fertile soils subject to waterlogging, but this does not preclude the effect these conditions may have on predisposing the plant to attack by parasitic organisms, as has been demonstrated by Menon *et al.* [18] for palms grown under waterlogged conditions in India.

With regard to the worst affected area, Avume to Keta, it is impossible to postulate a definite cause based on soil–water relationships despite the fact that some of the soils in that area possess an intolerant subsoil layer similar in physical effect to the marl layer of the Class III wilting soils in Trinidad [4]. But it has previously been reported that disease symptoms at Keta could not be produced by artificially reducing the root system nor could the disease be prevented by watering [1]; thus it seems likely that some other factors are involved. It may be that under the static ground-water conditions the accumulated roots decompose and lead to a state of auto-intoxication, for it has been noted here and elsewhere [19] that the lower roots of diseased palms are often rotten and impart an offensive odour to the ground water; this, however, may be the effect of the disease and not the cause. The effect of this might be expected to be more severe where water movements are mainly dependent on rainfall, and flooding and hard-pan occur; in general this has been found to be the case, and experiments are in progress to show whether such conditions can induce the disease.

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PLANT BREEDING IN THE CENTRAL RAINLANDS OF THE SUDAN, 1951–6

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Summary

Cotton breeding in the Sudan has been described by Knight [1]. The present article deals with the breeding of rain-grown sorghum and sesame. Problems of improvement in maize, groundnuts, sunflower, and kenaf (*Hibiscus cannabinus*) are also briefly mentioned.

WITH the exception of the initial stages in the sesame breeding programme, all the work here described was carried out at the Central Rainlands Research Station at Tozi (lat. 12° 30′ N., long. 30° 00′ E. app.). The soil at the station is typical of the clay plains of the Central Sudan, being a heavy alkaline (pH. 8·5–9·0) cracking clay (68 per cent. montmorillonite). The rains start in late May or early June and end in mid-October, so that there are marked wet and dry seasons. The annual rainfall is about 700 mm. [2].

The lack of surface-water supplies during the dry season of seven and a half months has prevented permanent settlement in most of the area. The majority of the sedentary peoples of the district are grouped in villages along the Blue and White Niles, which provide the only reliable perennial water supply. Smaller villages, situated near hills, are dependent for their water supplies on ancient or modern artificial catchment basins (*hafirs*).

In view of the sparse population, the large area involved, and the problems of water supply, the programme of the station was aimed at providing data for a mechanized system of farming.

Sorghum

In such a system, an improved sorghum variety could contribute to the crop's success in two ways. The establishment of the crop early in the season is facilitated if the variety is able to germinate with only a small amount of water and to grow rapidly in the initial stages, while mechanical harvesting calls for a plant of dwarf stature, resistant to lodging, and preferably with its head carried well above the flag leaf.

Material

Two sources of material were available: mixed local stocks and introduced types. Both are abundantly represented in the Tozi variety

[1] Formerly Ministry of Agriculture, Sudan.

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collection of over 800 accessions. The Sudan material, originally assembled by Evelyn [3], but added to more recently, covers the wide range of variability to be expected so near to the crop's centre of origin [4]. Varieties from French Equatorial Africa, the Belgian Congo, East Africa, and South Africa, together with many developed from African material in America, are also included. It proved impossible to divide this collection into groups on the basis of existing classifications. The majority of these, intended for local use only, did not accommodate the wide range of characters nor the various combinations in which they existed. Snowden's classification [5], though extensive, is based on herbarium material and uses botanical characters of little importance in the field. Thus when the classification is applied to this cross-pollinating crop under native cultivation in Africa the divisions are often artificial.

In an attempt to produce an agronomic classification of wide application, records were made during two seasons of head type, breadth of leaves, number of leaves per plant, plant height, number of days to 50 per cent. anthesis; and of pigmentation, shape, and size of glumes and grain.

While these data have not yet provided an adequate basis for a new classification, certain general conclusions may be drawn. Many characters (including numbers of leaves per plant, stature, grain size, and days to 50 per cent. anthesis) are either influenced by environmental factors, such as planting date, or else are associated in homologous series which can only be divided into arbitrary groups. Where either of these conditions exists or where both occur together, the characters cannot be used for classification. Head type appears to be a character devoid of these disadvantages. In the Tozi material five distinct groups were observed, the compact club, long narrow, semi-compact, open, and lax types respectively. The possibility of using the sub-umbellate panicle form as a character in such a classification should also be considered. The breadth of the leaves is little affected by the environment and the Tozi material fell into two groups of broad- and narrow-leaved varieties.

It is possible, however, that progress in the production of a classification of more than local application will depend on an advance in our knowledge of the cytogenetics of the species and of related forms.

Crop establishment

Agronomic experiments at Tozi have shown that early planting and high plant population give the best yield [2]. Also the application of a combined insecticide-fungicide seed dressing is required to ensure these high populations [6]. Under these conditions differences in rapidity of germination and initial growth were observed between varieties in the collection. In those varieties which germinated most rapidly the horny layer in the endosperm was but poorly developed. This observation is supported by work of Doggett [private communication] in Tanganyika, and similar conditions would appear to exist in maize [7]. The variety Wad Akr, which has given some of the highest yields recorded at Tozi, has a predominantly floury endosperm.

Mechanical harvesting

Initially, the most promising material appeared to consist of American varieties which had been bred for combine-harvesting. Variety trials showed that the most outstanding of these strains was Bonita × Hegari; Queensland Kalo and Plainsman have also given satisfactory yields.

Even these promising introduced strains were, however, consistently outyielded by mixed local varieties. The morphological variability of these latter stocks precluded their immediate use and a selection programme designed to obtain dwarf, uniform, and high-yielding strains was initiated.

The method used was a modification of the mass pedigree system of selection [8]. Initial single plant selections were made from small plots of the mixed local stock. The plants were subsequently grown in progeny rows for two or three years, and selections were made annually for combine characters and high yield. The most promising lines were then compared with the original stock in a variety trial and high-yielding and uniform progenies were bulked to form a multi-line strain.

This programme, which was started in 1951 with selections in the varieties Wad Akr and Feterita Maatuk, has now been extended to a range of fifteen varieties. Strains derived from Wad Akr have been grown and combine-harvested on a field scale during two seasons. On both occasions yields of 2,200 lb. per acre have been obtained. In trials, yields of the order of 3,500 lb. per acre have not been uncommon and on one occasion a yield of 4,500 lb. grain per acre was recorded.

While the selected Wad Akr is of uniform height, it has been found to be susceptible to lodging and somewhat too tall (4 ft. 3 in.) for convenience in combining. An unduly large bulk of leaf and stem has to pass into the drum of the combine, leading to slower threshing and so limiting combine speed, an important factor in costs.

More suitable strains derived from other varieties in the selection programme were available for testing on a field scale in 1956. Of these, Wad Yabis is similar to Wad Akr, though it may prove to be higher-yielding; while Wad umm Benein is 3–3½ ft. high with a well-extruded head and is generally similar in appearance to the American dwarf combine types. This latter strain has given high yields in progeny rows (3,300 lb./acre in 1954) and may prove to have a yield potential superior to both Wad Akr and Wad Yabis.

Under the dry conditions which prevail in the Central Sudan during the harvest (Dec.–Jan.) varieties with thin stems which dry rapidly are particularly susceptible to lodging in which charcoal rot (*Sclerotium bataticola*) also plays a part.

Two crosses, originally made in America with the object of introducing the mechanical stem strength of Shantung kaoliang into two American combine types, have been grown at Tozi. While strains with a high degree of resistance to lodging have been obtained, yields have been low. The importance of these crosses is now considerably diminished since progeny-row methods have isolated, from local varieties, strains which appear resistant to lodging. These take two forms; the 'dry-stem' character, found in many American varieties, and an apparent immunity to charcoal rot.

Maize

(In collaboration with Prof. A. H. Bunting, Reading)

Variety testing in maize originally started at Tozi in 1952, but was subsequently suspended since all strains gave low yields (up to 400 lb./acre). The demonstration, in 1954, of a marked response in this crop to nitrogen, phosphate, and zinc, suggested that the examination of a range of introduced material might usefully be undertaken once again. Consequently, in 1955 thirty-four varieties from South Africa, Southern Rhodesia, and the United States were compared in rows or small plots with a local strain, Karima. All received nitrogen and phosphate fertilizer placed with the seed; and 100 gm. of zinc sulphate in 10 gallons of water per acre was sprayed on the crop after emergence, using a wetter. Most of the varieties were hybrids and included a range of forms from early dwarf to tall late types (tasselling 35–51 days, maturity 76–102 days, height 5·25–8·48 ft.). The yields ranged from 1,530 lb. per acre for Karima (the local variety) to 3,850 lb. per acre for S.A. 11. The most successful varieties were in general intermediate in height and maturation time. All the higher-yielding varieties with the exception of two South African open-pollinated strains (Golden Beauty and Kalahari Early Pearl) were either top cross or double-cross hybrids. In the same season the local variety, supplied with nitrogen, phosphate, and zinc, yielded about 1 ton per acre over a 6-acre field.

After harvest the soil under a maize crop is still moist from 12 in. downwards. Maize (like sesame) thus appears to be an inefficient extractor of water at Tozi, to which may be related its inability to supply its needs for nutrients. In no other crop has a response to zinc or any other minor element been demonstrated at Tozi.

While variety trials, agronomic investigations, and field cropping will still require much additional work, the demonstration that yields of over 1 ton per acre (which would cover the cost of fertilizer and spraying with zinc sulphate) can be obtained, seems to open up a new prospect for maize growing on the clay plains of the Sudan.

Sesame

As with sorghum, the principal object of the breeding work in this crop is to provide an indehiscent variety which could be harvested mechanically. Since it appeared that this would involve a lengthy programme, an attempt was also made to improve dehiscent material for hand harvesting by existing native methods. The two parts of the programme should eventually provide complementary parental material for further work.

Dehiscent stocks

Two groups of dehiscent varieties have been tested and used in crosses: early-flowering dwarfs, and local varieties of medium-flowering period. Varieties in the former group have not given good yields but have proved valuable as breeding material. The most promising local variety at present available for production purposes is Mafaza Light which, in

1953, yielded at the rate of 1,380 lb. per acre in observation plots and has also been the highest-yielding variety in trials conducted in the two subsequent years. Gideim, a variety from the Ingessana Hills, about 100 miles south of Tozi, also yielded well (713 lb./acre; Mafaza Light 826 lb./acre) in the 1955 sesame variety trial.

In an attempt to improve the local varieties a dwarf, unbranched, early-flowering American variety, K. 10, which has three capsules per axil and a high capsule number per unit length of stem (short internodes), has been used as a parent. The object of the four crosses involved in this series is to retain as far as possible the large-branched habit of the local parent while increasing the number of capsules per plant. Selections are made for shorter internodes, three capsules per axil, and for capsule size.

By using irrigated plots during the dry season it has been possible to grow two generations each year. Thus during the rains of 1955 the progeny of these crosses, which were made in September 1952, reached the sixth generation. Single-plant material was then selected for progeny-row testing against the parental types.

Indehiscent stocks

The only source of true indehiscence at present known in sesame is a single plant found by Langham [9] in Venezuela in 1943. In this material certain deleterious characters such as semi-sterility, cupped leaves, deformed corollas, and low yield were associated with indehiscence. Attempts made in Venezuela [10] and U.S.A. [11] to transfer indehiscence to commercial types (used as the recurrent parent), by means of the back-cross technique, proved disappointing. Deleterious characters present in the original material were transferred with indehiscence.

In an attempt to investigate the indehiscent gene in a wider genetic background a multiple cross, involving thirty-two parental varieties, was made at Clemson Agricultural College, U.S.A. Some initial selections were made at Wad Medani in the Sudan in 1951 in a segregating population derived from this cross. The work was subsequently continued at Tozi, but the material, developed for selection under American conditions, has not provided lines which would yield well in the Sudan. It has, however, been possible to obtain strains which are indehiscent and free from undesirable characters and which yield up to 300 lb. per acre. These strains have now been crossed with local varieties.

Groundnuts

(In collaboration with Prof. A. H. Bunting, Reading)

For successful mechanical harvesting a groundnut variety must retain its fruit at harvest, have a compact fruiting habit, and a determinate and uniform maturation period. In certain circumstances dormancy, to prevent germination should harvest be delayed, and to control volunteer growth in the dry season, is also an advantage. The Tozi variety collection, filtered and classified by Bunting [12], and numbering over 250 uniform types, contained many strains suitable for mechanical harvesting. Consequently no breeding work was undertaken, the effort being confined to testing the yields of the more promising types and, more

recently, to making and testing selections within varieties in an attempt to improve yield.

Results obtained from trials conducted during the seasons 1953–5 are recorded in Table 1. In the 1953 and 1954 trials the levels of population,

TABLE 1. *Yield, Plant Population, and Yield per 1,000 plants in certain Groundnut Varieties, Tozi, Sudan, 1953–5*

Variety	*B 725*	*Stephenville 1838*	*Spanish Bunch*	*Natal Common*	*Barberton*
1953					
Population, 000/acre	43·2	39·6	30·8	29·7	16·6
Kernels, lb./acre	818	722	629	602	586
Yield/1,000 plants, lb.	19	18	20	20	35
1954					
Population, 000/acre	36·0	34·8	31·4	32·9	35·6
Kernels, lb./acre	1,099	871	859	979	1,208
Yield/1,000 plants, lb.	30	25	27	30	34
1955					
Population, 000/acre	58·8	60·2	61·0	57·3	61·4
Kernels, lb./acre	1,618	1,700	1,598	1,512	1,857
Yield/1,000 plants, lb.	27	28	26	26	30
Mean yield/1,000 plants, lb.	25	24	24	25	33

though variable, were all inside the range within which other experiments in those years suggested a linear relationship between population and yield. In 1955 the populations, though considerably higher, were reasonably uniform. It is therefore permissible to compare the yields per 1,000 plants which are also tabulated. These show clearly the consistent superiority of the variety Barberton which gave a mean yield over the three seasons of 33 lb. kernels per 1,000 plants against 24–25 lb. for the four other varieties.

The results of progeny tests of selected plants from both Natal Common and Barberton indicate that it should be possible to produce new strains of Natal Common (introduced into the Sudan for the first time in 1952) which would yield as well as present Barberton stocks. Barberton, which has been cultivated in the Sudan for about 20 years, showed little response to selection pressure.

Two other groups of varieties have also given promising yields. Long-season spreading-bunch types have out-yielded Barberton, but are not suitable for mechanical harvesting at Tozi, while Spanish varieties with a yield potential only slightly less than that of Barberton had a very compact fruiting habit which is highly desirable for mechanical harvesting. The possibility that the high plant populations which are necessary for maximum yield will favour the small Spanish types, calls for further investigation. Complete or nearly complete sets of the Tozi variety collection are now held by the Departments of Agriculture in Northern Rhodesia, Tanganyika, and Northern Nigeria.

A Spanish form with white kernels was bulked up at Tozi in the hope

that it might prove of interest for protein fibre production. It had also an exceptionally high oil content (52·5 per cent.). Although interest in the fibre is no longer active, it would seem useful to continue selection for yield in this or some similar form in case demand should develop in the future.

Sunflower

As in other parts of the world, the absence of suitable pollinating agents has prohibited the production of sunflower seed in the Central Rainlands of the Sudan. The produce contains many empty fruits and the yields are negligible. It was suggested [13] that self-fertilizing forms existed in the variety Giant Russian. To investigate this possibility initial selections were made from Giant Russian in 1952. These selections were grown in single-plant progeny rows during three subsequent seasons. The heads of the individual plants were enclosed in cloth bags which were held away from the florets by a wire frame. Thus external pollinating agents were excluded and it was impossible for pollen transference to be effected by the bag.

Under these conditions pure-breeding lines were isolated which gave a mean percentage fertilization as high as 94 per cent. The distribution of the percentage fertilization over all rows was such as to suggest a minor-gene basis of inheritance.

Kenaf fibre

Mass-selection methods have been used in material of local origin to obtain an unbranched variety producing its first flower about 5 feet above the ground. This height is reported to be the most desirable for mechanical processing of the crop [14, 15].

The material was originally collected from villages on the Blue Nile between Singa and Roseires where kenaf fibre is grown as a garden crop. The subsequent selections (in 1953 and 1954) have produced three uniform bulks flowering at $4\frac{1}{2}$ feet, 5 feet, and $5\frac{1}{2}$ feet respectively above ground level. Future work now turns upon an investigation of the quality and uniformity of the fibre in these groups.

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